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Characterizing Baghouse Performance to Control Asbestos Manufacturing Source Emissions

IIT Research Inst.
Chicago, IL

Prepared for

Industrial Environmental Research Lab.
Cincinnati, OH

Jul 81

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The report gives results of a study of the performance of a fabric filter baghouse operated at several levels of important parameters. The primary measure of the effectiveness of control was the fiber concentration in the baghouse effluent, since overall mass efficiency is too high to detect small differences. EPA Method 5 was used to collect the samples, and the analyses were performed using an electron microscope. The tests performed showed that the optimum conditions for asbestos fiber control involve using long intervals between shakes to allow the filter matrix to build on the bag. No adverse effect on pressure drop was detected, while a 5 fold reduction in emission was demonstrated.

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CHARACTERIZING BAGHOUSE PERFORMANCE TO CONTROL ASBESTOS MANUFACTURING SOURCE EMISSIONS

by

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Contract No. 68-03-2558

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FOREWORD

When energy and material resources are extracted, processed, converted, and used, the related pollutional impacts on our environment and even on our health often require that new and increasingly more efficient pollution control methods be used. The Industrial Environmental Research Laboratory - Cincinnati (IERL-Ci) assists in developing and demonstrating new and improved methodologies that will meet these needs both efficiently and economically.

The project described in this report is a product of the above efforts. It was undertaken to demonstrate removal efficiency of a fabric filter baghouse operated under various conditions. The baghouse removes asbestos fiber from the ventilation air to minimize occupational exposure of workers; the baghouse thus minimizes the emission of asbestos to the environment. The results are of value in the design and operation of fabric filter baghouses, particularly when recycle of ventilation air to conserve energy is one of the goals.

Further information concerning the subject can be obtained by contacting the Nonferrous Metals and Minerals Branch of the Energy Pollution Control Division.

David G. Stephan
Director
Industrial Environmental Research Laboratory
Cincinnati

ABSTRACT

A research program designed to improve the effectiveness of airborne asbestos fiber removal by baghouses during the commercial fabrication of asbestos-containing materials was undertaken.

A typical fabric filter baghouse control system was selected, automated, and modified to facilitate the use of the EPA Method 5 sampling method to monitor the output of the baghouse. A single-point near isokinetic inlet sampler was installed on each of four inlet ducts. The baghouse mass loading, the outlet fiber concentration, and operating parameters of the fabrication process were monitored for each of three baghouse operating parameters. Observations were made at three levels of each parameter. The baghouse research parameters were shake amplitude, shake duration, and shake interval.

Two test series were conducted. The first was a statistically designed test series, the results of which were interpreted using multiple linear regression analysis on the 1/3 factorial test design. The linear regression analysis showed shake duration to be the most important parameter, followed by the shake amplitude and the shake period. The results indicated that, at optimum shake interval and shake duration, a 5-fold improvement in asbestos fiber emission control was achieved. The second test series was run to determine whether extending shake intervals would procude an equivalent 5-fold reduction in fiber emissions and if the mass loading or waste type were more significant characteristics. Extending the shake intervals did result in low emissions, however no significant effect on control was achieved by extending shake duration. No detectable change in pressure drop was noted up to a 12-hour shake interval.

Statistical evaluation of the first test series data indicated interactions between the baghouse parameters. The fiber emissions were reduced at longer shake intervals. The major conclusion reached regarding asbestos emission control was that fiber emissions were minimized by the least frequent disturbance of the bags.

This report is submitted in fulfillment of Contract No. 68-03-2558 by IIT Research Institute under the sponsorship of the U.S. Environmental Protection Agency. This report covers the period from June 27, 1977 to September 30, 1979, when the work was completed.

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CONTENTS

Foreword iii
Abstract iv
Figures vii
Tables viii

1. INTRODUCTION 1

2. CONCLUSIONS AND RECOMMENDATIONS 2

3. PROGRAM BACKGROUND 3

Assessment of Particle Control Technology for Enclosed Asbestos Sources: Phase I 3
State-of-the-Art Asbestos Emission Control 3
Emission Data Collection and Analysis 4

Assessment of Particle Control Technology for Enclosed Asbestos Sources: Phase II 5

4. SITE SELECTION AND DEVELOPMENT OF TEST PLAN 7

Site Selection 7

Site Description 7

Experimental Test Plan 8

Experimental Procedures 9
Site Modifications 9

Sampling Procedures 11
Bag Change and Conditioning 12
Stabilization Period 12
Acquisition of Samples and Supporting Data 12
Operating Data 14

Analytical Methods 15
Electron Microscopy 15
Grid Preparation 15

5. EVALUATION OF BAGHOUSE TEST DATA AND DISCUSSION OF RESULTS . . . 17

Statistical Evaluation of Baghouse Test Data 17
Data Base Assembled 19
Assessment of Performance Differences Between Test Combinations 21

(continued)

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3/8"
PAGE NUMBER
EPA-287 (Cin.)
(4-76)

CONTENTS (continued)

Performance Equations 21
Results of Additional Tests 32

APPENDIX A: PLANT OPERATING AND SAMPLE QUALITY ASSURANCE DATA. 35

APPENDIX B: ANALYTICAL TECHNIQUES CONSIDERED FOR THE STUDY 59
Atomic Absorption Analysis 59
Optical Microscopy Analysis. 61

BEGIN FIRST LINE OF TEXT HERE
TYPING GUIDE SHEET
CENTER OF PAGE
TOP OF IMAGE AREA
DROPPED HEAD, BEGIN SECTIONS HERE

FIGURES

Number		Page
1	Output geometric mean fiber concentrations with 90 percent confidence intervals for all combinations	22
2	Shake duration vs. baghouse output--based on Equation 2 with 90% confidence band	24
3	Period between shakes vs. baghouse output--based on Equation 2 with 90% confidence band.	26
4	Shake amplitude vs. baghouse output--based on Equation 2 with 90% confidence band.	27

9-1/8"
BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"

PAGE NUMBER
EPA-287 (Cin.) (4-78)

TABLES

Number		Page
1	Specifications of Demonstration Baghouse	8
2	Controlled Factors and Their Levels	9
3	Experiment Design	10
4	Baghouse Inlet Ducts	13
5	Test Parameters and Their Levels	18
6	Experimental Design	18
7	Definition of Variables and Covariates	20
8	Statistics on the Concentration of Asbestos Fibers in Baghouse Effluent Air by Combination	20
9	Candidate Independent Variables for Equation Construction	23
10	Detailed Information on Equation 4	25
11	Detailed Information on Equation 5	25
12	Total Correlations Between Predictive Variables and the Dependent Variable Y2	27
13	Summary of Loading Data Obtained During Phase I	29
14	Comparison of Baghouse Pressure Drop to Experimental Parameters and Fiber Output Concentration	32
15	Inlet Loading and Outlet Fiber Concentration: Phase II	34
(Appendix A)		
A-1	Isokinetic Sampling Data and Calculation	36
A-2	Plant Emission Rate Data	40
A-3	Outlet Fiber Concentration	52
A-4	Cumulative Frequency Distribution of Lengths: Series I	55
A-5	Cumulative Frequency Distribution of Lengths: Series II	58
(Appendix B)		
B-1	Atomic Absorption Analysis on Effluent Samples	60
B-2	Atomic Absorption Analysis on Bulk Waste Samples	61
B-3	Atomic Absorption and Royco Data Comparison	62

SECTION 1

INTRODUCTION

Processes involving dry asbestiform minerals are known to produce significant quantities of waste materials capable of releasing airborne asbestos fibers. Airborne asbestos fibers have been associated with asbestosis and other respiratory diseases. The prevalent control device used to minimize the emission of airborne asbestos fibers to the environment is a fabric filter used in a form known as a baghouse.

This report describes a field research program whose objective was to minimize asbestos fiber emissions from baghouses. The program demonstrated that even a baghouse with high mass efficiency, emits literally billions of fibers per hour. Although current data do not permit the quantitation of the asbestos fiber health effects, it is prudent to maximize the control of asbestos emissions using the most feasible, economical and effective methods available. Further, since asbestos fibers are implicated in the development of diseases with 20-40 year latency periods, and since no threshold exposure value has as yet been defined, it is possible that even very small emissions could have a long-term impact on the national health.

Previous studies had shown that the fabric filters were the most common and effective method of controlling emissions from asbestos processes and that variations in the operating parameters could affect the degree of control achieved. In this study, a full-scale commercial baghouse was operated at specified conditions, and its degree of control measured. The objective of the study was to identify significant operating parameters and to determine what conditions provide maximum control of asbestos fiber emissions. Since the variations on a mass basis are small, the fiber count method was used.

SECTION 2

CONCLUSIONS AND RECOMMENDATIONS

The single most important variable in the level of emissions from a baghouse is the duration of the shake time for the bags during the cleaning operation. The next variable in importance is the amplitude of the shake, followed by the shake period. These three variables account for about 40% of the output variability from the baghouse.

The interactions between the three parameters of shake period, shake amplitude and shake duration are important in operating a baghouse. The measured fiber emission rate from a baghouse is dependent on both the type of material being processed and on the process rate.

The lowest values of baghouse output measured were 6 million fibers/m^3 and the highest 32 million. The lowest value showed fiber concentration of 200,000 fibers/m^3 > 5 μm on the average. However, one sample included in this average approximated the OSHA limit of 2 million fibers/m^3 of air. Effluent fiber counts exceeding the current OSHA limit of 2 fibers/cc of air > 5 μm in length were numerous.

The lower concentrations of fibers emitted were achieved when the baghouse was operating at conditions which favored greater cake build-up on the bags. The combination was: short shake/small shake amplitude and long shake period. No detrimental effect on pressure drop was noted at the most efficient conditions. In fact, no correlation of performance with pressure drop was found.

The baghouse exit air fiber levels must be reduced below 100,000 fibers > 5 μm per cubic meter to be considered for recycle. In lieu of current optimum conditions as defined by this research, the baghouse alone cannot produce the levels of control required. Additional research is necessary to assess what, if any, control technology is capable of producing an emission of less than 100,000 fibers > 5 μm per cubic meter.

The use of statistical design techniques when evaluating or optimizing control device performance is recommended. Statistical designs for continuous data are quite efficient to use and provide cost effective programs. The data obtained on a statistically designed program will provide, at a minimum, guidance for future work and trends; at its best, when all assumptions are correct, the maximum information is extracted from the data.

SECTION 3

PROGRAM BACKGROUND

The study whose results are presented in this report has origins in past projects done at IITRI and in the EPA's continued interest in the improvement of control technology for asbestos fiber emissions from industrial sources. The initial effort was a two-phase program performed under EPA Contract No. 68-02-1353. Phase I results are reported in EPA 650/2-74-088 and Phase II results in EPA 600/2-76-065. In the remainder of this section, the principle findings of these programs are restated.

ASSESSMENT OF PARTICLE CONTROL TECHNOLOGY FOR ENCLOSED ASBESTOS SOURCES: PHASE 1 (DEFINITION AND MEASUREMENT)

The objectives of particle control technology assessment described in this section were twofold. The first objective of the study was to determine the types of particulate control used in the control of asbestos emissions. The second objective was to provide measurement of the efficiency of the control method(s) for asbestos fibers found most prevalent.

State-of-the-Art Asbestos Emission Control

An extensive literature search on the control of particulate matter emissions was carried out and the general types of control found were evaluated for suitability for control of asbestos fibers. The bibliography assembled was used in conjunction with a survey of users of asbestos fiber emission control devices to provide a state-of-the-art assessment.

Four basic approaches to the control of asbestos emissions from industrial sources were found in the literature survey. These four were:

- cyclones which operate on an aerodynamic separation principle using centrifugal forces,
- wet scrubbers which operate on a variety of droplet interception of particulate mechanisms,
- electrostatic precipitators which operate on the principle of collecting the particulates, which have been charged in a corona, on a grounded plate, and
- baghouses, which operate on the principles of filtration.

The baghouse was found to be the predominate device used in the United States for asbestos fiber emission control with regard to both suitability and

use. There are several reasons why over 80% of the control devices in use are baghouses. Among the technical reasons favoring the use of fabric filtration in various baghouse configurations are:

- the availability of fabric types for most conditions of use,
- the flexibility of baghouse designs and cleaning mechanisms to allow for a variety of process inputs,
- the capability of a baghouse to maintain its high efficiency over a wide range of loadings,
- the turndown capacity of a baghouse, that is the ability of a baghouse to maintain its efficiency at reduced airflow rates, and
- the ability of a baghouse to provide control meeting EPA regulations.

Based on the findings two techniques were capable of providing adequate control, the baghouse and the electrostatic precipitator (ESP). The baghouse is favored for the technical reasons already specified, while the ESP has lower investment and operating costs which are insufficient to justify the process modification needed to make them technically feasible to apply. Thus, the baghouse was the most common and most suitable technique for the control of asbestos emissions.

The full report on Phase I provides significant statistics on subcategories of design, cleaning methods, waste disposal and the number of plants, and quantities of asbestos processed in active industrial baghouses.

Emission Data Collection and Analysis

Upon completion of the state-of-the-art survey, preliminary emission data was collected at five industrial sites: two asbestos refining mills, two asbestos cement product plants, and one asbestos textile plant. The purpose of the emission data was to establish a data base to measure the efficiency of baghouses and to permit the estimation of ambient air asbestos fiber concentrations in the vicinity of asbestos processing plants.

Two sampling techniques were used, the first a standard EPA Method 5 technique for particulates, and the second a modified Method 5 to permit collection of samples suitable for fiber size analysis.

The sample analyses were carried out on two bases. The standard sample analyses were used to compute the total mass removal efficiency, which was in all cases greater than 99.99%. The analyses of the samples collected for fiber size analysis were performed using both the optical microscope and the transmission electron microscope.

The results of the microscope analysis showed a range of maximum penetration or of minimum efficiency. The size of fibers achieving maximum penetration was submicron, while the concentration was on the order of

10^8 fibers/m^3. This effluent air concentration compares to 10^6 fibers/m^3 for the "OSHA" fibers visible by optical microscopy.

The total number of fibers measured were used as input to estimate the downwind fiber concentration by using the Binomial Continuous Plume Dispersion Model as described by Turner. The results of these calculations showed a rise in fiber concentration attributable to the baghouse emissions to a distance of about 10 km during the day, with concentrations higher by about an order of magnitude at night.

ASSESSMENT OF PARTICLE CONTROL TECHNOLOGY FOR ENCLOSED ASBESTOS SOURCES: PHASE II (BAGHOUSE PARAMETERS)

In this section, a brief description of a pilot scale experiment, designed and evaluated by the extensive use of statistical techniques, is presented. The objective of the pilot study was to define significant parameters in baghouse operation from the point of view of minimizing the output from a baghouse.

A Wheelabrator Dustube Dust Collector*, modified to be operated with two (2) bags, was used to evaluate selected parameters. The shake system for bag cleaning was an automatic, mechanical type, and the operating cycle was also automated.

The parameters evaluated were categorized as pre-baghouse, baghouse and post-baghouse options. The specific set of options evaluated within the time, cost and technical limitations of the study were:

- Pre-Baghouse
    - Relative Humidity
    - Air Flow
        - Rate
        - Rate Variability
    - Dust Loading
        - Total Load
        - Load Variability
- Baghouse
    - Bag Type
    - Air to Cloth Ratio
    - Shake Cycle
        - Amplitude
        - Duration
        - Frequency

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* N 1 Model 70-BC

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- Post-Baghouse
  - Exhaust Recycle During Stabilization
  - Series Operation

The analyses of the outlet samples collected using an EPA Method 5 train were performed using both optical microscopy and Transmission Electron Microscopy (TEM). The results of the analyses and statistical evaluation of the data led to a set of qualitative conclusions. The results were not defined as a set of operating equations, since the pilot experiments were not prescaled to industrial standards and the variability of the analytical data was quite high.

The conclusions were:

- Relative humidity may affect the longer fibers' filterability and high relative humidity has an adverse effect on many bag fabrics.
- Total dust loading is less significant than type of dust.
- Cotton fabrics seem equal in control capability and superior in resistance to relative humidity.
- High air to cloth ratios promote removal of fibers.
- Higher shake amplitudes produce lower outlet concentrations.
- Shorter shake duration produces lower outlet fiber concentrations.
- Longer time periods between shake cycles (low frequency) produces lower outlet fiber concentrations.
- Exhaust recycle during bag stabilization may dramatically reduce outlet fiber concentration during stabilization of new bags (approximately 24 hours of operation).
- Two baghouses in series are not significantly more efficient than a single, stabilized baghouse.

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SECTION 4

SITE SELECTION AND DEVELOPMENT OF TEST PLAN

The process of site selection, modification, and development of a statistically designed experimental test plan is critical for a successful field demonstration. A test plan to evaluate the influence of the baghouse operating parameters on fiber removal is equally important.

SITE SELECTION

The first Task in planning for a field demonstration test was to locate and obtain permission to use a suitable site. The following major criteria were developed:

- cotton sateen fabric compatible or specified for the baghouse,
- cleaning by mechanical shake,
- automated cycle or relative ease of automation,
- process with continuous or frequent asbestos emissions to baghouse,
- cooperative management willing to assist in sampling program to the extent of allowing modifications to baghouse procedures and accept changes in plant routine required by various cycles,
- reasonably well-maintained baghouse.

The above criteria led to some difficulties in obtaining a site for the demonstration study. The two areas creating the most difficulty were: many users of baghouses have emissions from the asbestos processing areas of the plants only infrequently and most managements were unwilling to allow IITRI to specify operating conditions of the baghouse. Also when a suitable site was located, it required IITRI to design and install automation on the baghouse.

SITE DESCRIPTION

The demonstration site was located in Brooklyn, N.Y., on the roof of one of the largest independent fabricators and distributors of mineral fiber products for electrical installation systems, architectural panel systems and of hospital/laboratory furniture components. The manufacture, assembly and finishing of these products involves almost continuous drilling, cutting, sanding and machining of asbestos containing composition board, similar to transite.

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The baghouse, as originally installed, was a single compartment, 220 bag baghouse with 4 inlet ducts. The nominal air filtration rate was 340 m^3/min at an air to cloth ratio of (0.81 m^3/min)/(m^3 of cloth). Complete specifications of the baghouse are given in Table 1.

TABLE 1. SPECIFICATIONS OF DEMONSTRATION BAGHOUSE

	Baghouse	Bag
Height	3.4 m*	---
Width	2.9 m	0.2 m
Length	4.9 m	3.0 m

Number of bags: 220 Fabric and Style: Cotton Sateen #9660

Area of bags: 418 m

Flow Rate: (Nominal) 340 m /min
(Actual) 323 m /min

Air to Cloth Ratio (m /m): (Nominal) 0.81
(Actual) 0.77

Inlet: 4 ducts, bottom inlet

Discharge Air: Top-exhaust to atmosphere

Solids: Bottom discharge, auger to disposal

Bag Installation: Bags are hung from the top shake frame and sealed by clamps to a fixed bottom plate.

Shake is approximately 15x/min operated by a cam. The shaker has two motors at either end of the baghouse.

* Height excludes solids storage and auger.

At the time of selection, the plant operated on a 12-hour cycle with baghouse operations ending with a 5 minute shake at the end of the work day. The shake was performed by manual operation of the shake motors, followed by operation of the screw to remove the day's accumulation of waste.

EXPERIMENTAL TEST PLAN

Based upon the results of data obtained from a pilot scale, laboratory operated baghouse experimental study, a plan to determine the optimal combination of three parameters was formulated. The plan is based on acquiring data for statistical analysis for a 1/3 factorial design involving 3 factors at 3 levels. With the inclusion of one replicate experiment, a 10 test plan resulted.

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The three parameters selected for the controlled factors were:

1. Length of shake cycle
2. Duration of shake cycle
3. Amplitude of shake

The levels are given in Table 2, and the combination and the planned order of the tests are given in Table 3.

The data required to evaluate the statistical design is the outlet concentration of fibers from the baghouse. The data is input to a stepwise regression analysis program which first determines the statistical significance of a parameter, and then uses the levels of the factors and the experimental output data to fit the coefficients to equations. The overall equation resulting describes the optimal operating conditions for control of asbestos emissions from the baghouse.

TABLE 2. CONTROLLED FACTORS AND THEIR LEVELS

Factor	Levels		
Period between shake	(1) 1 hr	(2) 2 hrs	(3) 4 hrs
Duration of shake	(1) 10 sec	(2) 20 sec	(3) 40 sec
Amplitude of shake	(1) 1.75 cm	(2) 3.50 cm	(3) 7.00 cm

EXPERIMENTAL PROCEDURES

Site Modifications

After the test plan had been formulated, several modifications were required to permit completion of the test plan at the selected site. The modifications were:

- Partition the baghouse; primarily to reduce the cost and time needed during rebagging operations between experiments.
- Automate baghouse cycle; installation of timers to allow for control of the time interval between shakes, and of the shake duration.
- Shake amplitude controls; installation of a modified cam to allow changing the amplitude of the shake.
- Ducting modification; installation of ducting and plenum to enclose the exhaust air from the experimental compartment of the baghouse.

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TABLE 3. EXPERIMENT DESIGN

Factor Combination	Order of Testing	Levels of Controlled Factors		
		Period Between Shake, hr	Duration of Shake, sec	Amplitude of Shake, cm
1	7	1	10	7.00
2	1	1	20	1.75
3	9	1	40	3.50
4	4	2	10	1.75
5	6	2	20	3.50
6	3	2	40	7.00
7	2	4	10	3.50
8	8	4	20	7.00
9	5	4	40	1.75
10*	10	2	20	3.50

* Combination 10 is a replicate of combination 5.

The first modification was a convenience. However, a more complete description of each of the other three modifications is presented below:

Automation of Baghouse Cycle--

Automation of the baghouse and shake cycles involved the installation of relays needed to allow a timer to interrupt the operation of the blowers, as well as, a complex timer system. Control of both cycles involved three timers. The primary timer both shut down the 4 blowers to the baghouse and initiated the cycle of the other two timers. The second timer provided a 1 minute "settling period" for the baghouse prior to the shake. After a 5 minute shutdown, it reset the primary baghouse cycle timer and the relays controlling the blowers, permitting the process to restart.

The third timer provided the means to control the shake duration. The timer contained several adjustable cams, three of which were set to the desired shake duration. Selection of the duration for a shake could be accomplished by setting an external, manual switch. During this study, the shake intervals were set at 10, 20, and 40 seconds and at 32, 108, and 220 seconds.

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Shake Amplitude Controls--

The baghouse shake mechanism consisted of two motors, each attached to the support frame by a mechanical linkage. The original shake amplitude was 7.5 cm (3 in.) and was controlled by a fixed cam. The desired modification was achieved by installation of a new cam on each motor output with 3 sets of holes. The holes provided shake and amplitude of 1.75, 3.5 and 7.0 cm. The shake amplitude was adjusted as needed during the course of the program.

Ducting Modifications--

The baghouse selected for the test program was constructed to discharge directly to the air through two slots with "flapper" covers along the length and near the top of the baghouse. Since such an arrangement makes it difficult to obtain representative samples, IITRI elected to further modify the baghouse. As pointed out before the baghouse was partitioned, the slot on one side of the experimental compartment was sealed, and a plenum (1.2 x 1.2 x 2.4 m) was installed on the other. A 0.6 m duct was attached to the bottom of the plenum, and at about 1 m above the roof a 90° elbow was used to bring the flow to the horizontal plane. A 10 m run of 0.6 m ducting was installed and the sample location was situated at about 6 m+ (10 diameters) from the elbow and 3.4 m (5 diameters min.) from the discharge. This ducting arrangement gives a velocity of approximately 10 m/sec, adequate to maintain all of the particles in suspension. The location of the sample port and the geometry was also designed to assure a flat flow profile, free of vortexes and disturbances.

To complete the modification, a damper was installed along the other half of the discharge slot adjacent to the plenum. The damper allowed balancing the pressure drop and the baghouse flow during sampling runs.

SAMPLING PROCEDURES

The general procedure followed for each test series is described in the following paragraphs. A precis of the procedure consists of these steps for each test series:

- Bag Change
- Cycle Selection
  - Cycle Interval
  - Shake Duration
  - Shake amplitude
- Stabilization Period - 1 week
- Test Sample Series - 1 week
  - Inlet Samples (mass basis)
  - Outlet Samples (EM analysis)
  - Data Accumulation
    - Pressure Drop

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(Data Accumulation--continued)

- Material Type
- Quality Control on Samples

The details of each step in the test sequence follow in order:

Bag Change and Conditioning

The bag changes were performed by a subcontractor on Saturday afternoon upon completion of the week's production schedule. One hundred and twenty new cotton sateen bags (Style 9660) were installed, and, if required by the new test sequence, the cams on the shaker drives were reset to the required position by the subcontractor.

The cycle length was adjusted by setting the dial of the master timer to the desired interval less the 5 minutes of the shake portion of the cycle. After initially setting the circuits for the preselected shake durations, the duration specified by the schedule was set using the manual switches.

Verification of the baghouse bag changes was achieved by personnel employed at the site, while IITRI personnel verified the cycle duration, cam setting, and shake duration upon arrival for the sampling week of the test sequence.

Stabilization Period

During work on a previous study, IITRI found that a 24-hour period was sufficient to eliminate the effect on the outlet concentration of new bags in a pilot scale installation. The total daily hours of baghouse operation at the field demonstration site approximated a 12-hour day. The plant operated on an 8-hour day with selected operations beginning early and others intermittently operating later.

To assure a 24-hour operation at the normal load, 3 days of operation were needed, and, for both convenience and to allow for holidays, a full week of stabilization was specified.

Acquisition of Samples and Supporting Data

Each sampling sequence was of one week's duration. On each day, the sample plan called for replicate samples to be taken, together with data to assure isokinetic sampling conditions on the baghouse outlet samples, proper flow through the inlet filters, and data on the pressure drop across the experimental compartment of the baghouse. Additionally, the type of material and operations at each inlet duct was monitored on a regular basis by the IITRI sampling personnel.

Baghouse Inlet Sampling--

Four inlet samples were taken with each run, one sample from each inlet duct. The samples were collected on preweighed filters using near isokinetic conditions which were achieved by using a suitably sized critical orifice for

flow control and a probe fabricated from copper tubing. Each inlet probe was field fabricated by swaging a piece of copper tubing of selected diameter which was then drilled to an inside diameter (ID) calculated to provide near isokinetic sampling velocities at the flow rate of the critical orifice. Tabulated values of the flow rates measured in each inlet duct, the sampling rate as well as the computed and actual nozzle size are given in Table 4.

TABLE 4. BAGHOUSE INLET DUCTS

Duct No.	Average Duct Velocity (ft/min)	Duct Diameter (in.)	Duct Flow Rate (cfm)	Percent of Total Flow (%)	Critical Orifice (ℓ/min)	Nozzle Diameter (in.)	Drill Size No.	Drill Size (in.)
1	2050	15	2515	22	4.9	0.124	30	0.128
2	3980	15	4883	43	15	0.156	22	0.157
3	3790	9	1675	15	15	0.160	20	0.161
4	1900	15	2331	20	4.9	0.129	30	0.128

As part of the effort to assure accurate inlet measurements, provision was made to measure the pressure drop (ΔP) across the filter. In the event that the ΔP across the filter rose to a point where significant loss of flow at the critical orifice would occur, the inlet filter was changed for that run. The total weight collected was then used in computing the inlet rate.

The weight collected on each filter was used with the integrated flow to compute the mass concentration in each inlet duct. The weighted average was then computed on the basis of the actual measured flow in each duct. The combined equation is given in Equation 1

$$C_I = \sum_{4}^{i=1} \frac{W_i}{(f_i T)} \cdot F_i \qquad (1)$$

where:

C_I = Inlet concentration; mg/ℓ

W_i = Weight collected in duct i; mg

f_i = Sampling rate, duct i; ℓ/min

T = Sampling time; min

F_i = Fraction of total flow, duct i; dimensionless

Baghouse Outlet Sampling--

The baghouse samples were taken using the technique and equipment of an EPA Method 5 train with minor modifications described below. The samples thus obtained were analyzed using Transmission Electron Microscopy (TEM), for which our detailed procedure is described in the Analytical Methods portion of this section.

The daily sampling runs were begun shortly after the plant began full production and was ended upon completion of 2 samples of the baghouse outlet. The outlet samples themselves were taken using an Aerotherm Acurex HVSS sample train operated at isokinetic conditions. The target sample volume was approximately 9 m^3 (330 ft^3), thus in the 2 hr sample period the average flow rate was 78 ℓ/min of air (2.8 ft^3/min).

There were several deviations from standard Method 5 procedures. The major deviations are listed and described below.

1. Flow Rate
2. Total Sample Volume
3. Sampling Time
4. Single Point Sampling
5. Omission of Impinger Train (No Moisture Determination)

The majority of the deviations are site or goal specific. The changes in the flow rate and the sampling time, and thus in the sample volume, were determined by preliminary experimental trials, to assure samples containing sufficient material for the analytical technique used on the program.

The other two significant changes were adopted to simplify the procedures and reduce the effort needed. The rationale for single point sampling was based on the fact that the duct size was selected prior to installation using prior knowledge of the sampling needs. A velocity sufficient to maintain asbestiform minerals and other particulates in suspension was specified, and the length of the duct was such that the distance criteria for upstream and downstream disturbances were met. Additionally, preliminary pitot tube traverses revealed a flat flow profile, as designed. This allowed selection of a single fixed point for isokinetic sampling proportional to the outlet flow rate.

The basis for omission of the impinger train was twofold. The low moisture content in the airstream contravened the need to dry the sample for protection of the sampling train and there was no need to determine the concentration on a dry basis.

Operating Data

During each sampling period, data were taken every few minutes on the operating conditions of the inlet samplers, the outlet samplers, the materials being processed by the plant and the pressure drop across the baghouse. Most of the data taken was used to compute the percent of isokinetic flow main-

tained on the outlet sample and verify proper flow through the inlet mass samplers. However, the data on material being processed and on the baghouse pressure drop were pertinent to the objectives of the program.

ANALYTICAL METHODS

Electron Microscopy

The primary analytical method used on the program was transmission electron microscopy (TEM). The TEM procedure used is documented in EPA 600/2-77-178. In the EPA methodology fibers are counted and sized by TEM microscopy after the fibers are transferred from the Nuclepore^{R} filter membrane to a TEM grid.

Grid Preparation

The first step in preparing a Nuclepore^{R} filter membrane for electron microscopy is carbon coating a section of each filter sample in a vacuum evaporator. The carbon film is applied by continuous evaporation of a carbon rod to form a continuous film. Next, a 0.3 mm diameter circle is punched from each carbon-coated filter and placed (coated side down) on a 0.3 mm, 200 mesh carbon-coated electron microscope grid.

The Nuclepore^{R} membrane is dissolved away using spectroscopic grade chloroform in a Jaffe-Wick washing technique. In this technique, the grid is placed on a 400 mesh stainless steel screen resting atop a stack of filter paper (Whatman^{R} #4) situated in a petri dish in which the solvent level is maintained to saturate the filter papers. Fresh solvent travels up the filter paper by capillary action and slowly dissolves the Nuclepore^{R} filters to complete the transfer of the sample to the EM grid. This process takes 24 to 72 hours depending on the history of the filter. The grids are then stored in identified slots in labeled grid storage boxes until they are analyzed.

The grids are inserted into the electron microscope and randomly selected grid openings are counted at a photographic magnification of 20,000X, (16,000X on the observation screen). Data on the fibers are recorded by counting all the fibers in each of several grids until either 10 grid openings or more than 100 fibers have been enumerated and sized.

The fiber number concentration is computed from Equation 2.

$$C_F = 5.5 \times 10^3 \frac{F_C \cdot A_F \cdot P_R \cdot T_S}{G_O \cdot V_S \cdot P_S \cdot T_R} \qquad (2)$$

where: C_F = fiber concentration, No. of fibers/SCM

F_C = fiber count, No. fibers

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G_O = no. of grid openings used to obtain fiber count

A_F = active filter area, cm

V_S = volume sampled measured by sample train, acf

P_R = reference pressure, 1 atm

P_S = sampling pressure, atm

T_S = sampling temperature, ^oK

T_R = reference temperature, 294.4^oK

EPA-287 (Cin.)
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SECTION 5

EVALUATION OF BAGHOUSE TEST DATA AND DISCUSSION OF RESULTS

The baghouse operating parameters were evaluated as described in the experimental plan using a linear regression technique. The results of the first series are discussed in light of previous studies and of the peripheral data taken at the site. The purpose, results, and discussion of the second test series of three tests done during 1979 follows this portion of the report. The results of data taken on the baghouse pressure drop are briefly presented and discussed.

The data base (including the analysis associated with each sample, fiber size distributions for each sample, the individual data on the inlet samples associated with each outlet sample, and the data and computed % of isokinetic sampling rate collected during the single point EPA Method 5 runs) are presented in the Appendix to this report. The bulk of the tables are included for completeness and to support conclusions. Where needed, an example is used in the text.

STATISTICAL EVALUATION OF BAGHOUSE TEST DATA

The primary objective of the fractional factorial statistical evaluation was to define guidelines for the optimum operation of baghouses for control of asbestos emissions. This was done on a full scale baghouse in use on an actual operation generating asbestos emissions. The parameters selected for investigation were:

- the period of time between shake cycles,
- the duration of the shake cycle, and
- the shake amplitude.

Three levels of each factor were tested and the levels are given in Table 5. The level of each of the parameters are equally spaced on a logarithmic scale; the value of the second level being twice that of the first, and the value of the third level being twice that of the second.

The spacing of the levels was chosen to facilitate use of the selected experimental design, a 1/3 fractional factorial design for three controlled variables at three levels with one replicate test. The experimental design

TABLE 5. TEST PARAMETERS AND THEIR LEVELS

Parameter	Levels		
Period between shakes	(1) 1 hr	(2) 2 hrs	(3) 4 hrs
Duration of shake	(1) 10 sec	(2) 20 sec	(3) 40 sec
Amplitude of shake	(1) 1.75 cm	(2) 3.50 cm	(3) 7.00 cm

used is presented in Table 3. The levels of the controlled factors were specified for each of the test combinations. Combination 10 was a full replicate of Combination 5. These two combinations represent the "central point" of the design; i.e., each factor was at its intermediate level.

In addition to the levels, the planned order of the 10 tests is given under the heading Test No. in Column 2 of Table 6. The order was generated using a random permutation of the integers 1 through 10.

TABLE 6. EXPERIMENTAL DESIGN

Factor Combination	Test No. (Order of Testing)	Levels of Controlled Factors: Period Between Shakes, hr	Duration of Shake, sec	Amplitude of Shake, cm
1	7	1	10	7.00
2	1	1	20	1.75
3	9	1	40	3.50
4	4	2	10	1.75
5	6	2	20	3.50
6	3	2	40	7.00
7	2	4	10	3.50
8	8	4	20	7.00
9	5	4	40	1.75
10*	10	2	20	3.50
11**	11	12	300	7.00

* Combination 10 is a replicate of combination 5.

** Combination 11 represents standard baghouse practice; this is not part of the experimental design, and was not included in the linear regression.

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An additional condition was tested and is labeled Test 11, Combination 11 in Table 6. This represents the baghouse at normal operating conditions with a single extended shake period at the end of a 12-hour work day. The shake amplitude is 7.00 cm, equal to the high level in the design.

Data Base Assembled

During the first series of tests on the program a data base was assembled permitting statistical analysis of the three baghouse parameters, monitoring of the baghouse condition, baghouse inlet loading, and data permitting a check on the validity of the samples.

All of the data were associated with 93 individual samples taken during the test program. The specific data base used in the statistical analysis consisted of fiber concentration in no. of fibers/SCM. The data was the result of electron microscopy (EM) of each of the 93 samples obtained. Additionally, each of the inlet loading values obtained from all but combination 2 were also entered into the analysis as possible co-variate variables. The values of the fiber counts normalized using Equation 3, and the normalized fiber count and its natural logarithm were also considered as variables. The definition of dependent variables and co-variate candidate variables are given in Table 7.

$$F_n = 100\ F_c/L \qquad (3)$$

where: F_n = normalized fiber count, 10^7 fibers/SCM

F_c = measured fiber count, 10^7 fibers/SCM

L = inlet loading during the test, gram/minute

Prior to the linear regression analysis of the design, statistics on each of the combinations were obtained. These statistics are presented in Table 8.

These statistics were used to verify the homogeneity of the fiber counting data and various transforms. The variance of the fiber count data varied widely from combination to combination ($P > .001$). The variance of the square root transform also fluctuated ($0.10 > P > 0.05$), while the log transform was more stable ($0.3 > P > 0.2$). On the basis of Bartlett's test, the log transform was considered suitable for use in obtaining a pooled estimate of the standard deviation. The estimated pooled standard deviation obtained on the basis of 81 degrees of freedom was $s = 0.49$.

The point estimates of the geometric means, the log values used, and the 90% confidence limits are also given in Table 8. The confidence limits are based on the pooled variance and a standard value of student's t. For 81 degrees of freedom and $P = 0.10$, $t = 1.665$.

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The values of the geometric means with 90% confidence limits are

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TABLE 7. DEFINITION OF VARIABLES AND COVARIATES

Variable Category	Symbol	Definition
Dependent	Y1	Number of asbestos fibers (in units of 10^7) per standard cubic meter of baghouse effluent air
Dependent	Y2	Ln (Y1)
Covariate	Z1	Total plant emission rate (baghouse input), g/min
Covariate	Z2	Ln (Z1)
Dependent	Y3	Normalized fiber count: 100 (Y1/Z1)
Dependent	Y4	Ln (Y4)

TABLE 8. STATISTICS ON THE CONCENTRATION OF ASBESTOS FIBERS IN BAGHOUSE EFFLUENT AIR BY COMBINATION

Comb. No.	No. of Samples	Fiber Concentration (10^7 Fibers/SCM of Air)				
		Mean	Standard Deviation	Geometric Mean	90% Conf. Limits* Lower	90% Conf. Limits* Upper
1	5	1.242	0.960	1.008	0.700	1.454
2	8	3.493	1.458	3.183	2.424	4.179
3	9	3.506	1.549	3.228	2.459	4.239
4	10	1.019	0.334	0.974	0.752	1.261
5	8	2.796	1.190	2.532	1.897	3.379
6	10	2.073	0.849	1.933	1.493	2.503
7	8	1.846	0.578	1.751	1.312	2.388
8	6	2.186	1.172	1.850	1.325	2.582
9	10	2.852	1.872	2.416	1.866	3.128
10	9	2.885	0.673	2.802	2.134	3.679
11	9	1.324	0.986	1.086	0.827	1.425

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presented in Figure 1.

Assessment of Performance Differences Between Test Combinations

Examination of Figure 1 shows that significant differences between test combinations existed. The geometric mean fiber concentration varied (in units of 10^7 fibers per SCM) from a high of 3.23 to a low of 0.97, more than a threefold range. Three of the combinations, i.e., 1, 4, and 11, had fiber emission concentrations that were significantly lower than those of all the other combinations, although the three did not differ significantly among themselves. These observations, made by inspection of Figure 1, were confirmed by t tests for differences between the geometric means. For any two baghouse tests, the number of samples obtained were denoted by N_1 and N_2, respectively, and the mean values of log fiber output concentration by $\overline{Y2}_1$ and $\overline{Y2}_2$. Then the statistic for determining the significance of the difference between the means (which it was assumed could be either positive or negative) is

$$t = |\overline{Y2}_1 - \overline{Y2}_2| / (s\sqrt{1/N_1 + 1/N_2})$$

The chance probability, P, corresponding to the magnitude t and the 81 degrees of freedom available for the estimation of the standard deviation s can be looked up in a table of percentage points of the t distribution. Using this t test, it was found that each of the three combinations--1, 4, and 11--had values of $\overline{Y2}$ that were significantly lower ($P \leq 0.5$) than the values of $\overline{Y2}$ for all the remaining combinations. On the other hand, pairwise comparison of combinations 1, 4, and 11 revealed no significant difference in the values of $\overline{Y2}$, P ranging from about .6 to .9.

No simple pattern of relationships between the output fiber concentration and the levels of the three controlled shake variables is strikingly apparent in Figure 1. Both combinations 1 and 4 had short-duration shake cycles of 10 sec, the former with a short intercycle period of 1 hr and a long amplitude of 7.0 cm, the latter with an intermediate intercycle period of 2 hrs and a short amplitude of 1.75 cm. All of the tests with the 4 hr intercycle period or with the 20 or 40 sec cycle duration, yielded higher fiber concentrations than did combinations 1 and 4. In contrast, the benchmark combination, 11, which performed about as well as 1 and 4, is characterized by a relatively long intercycle time of 12 hrs and very long cycle duration of 300 sec.

Performance Equations

Further information concerning the effects of the controlled variables in the fractional factorial experiment (combinations 1-10) was obtained by constructing performance equations from the test data by the method of stepwise multiple regression.

Mathematical Model--

The model equation has the form:

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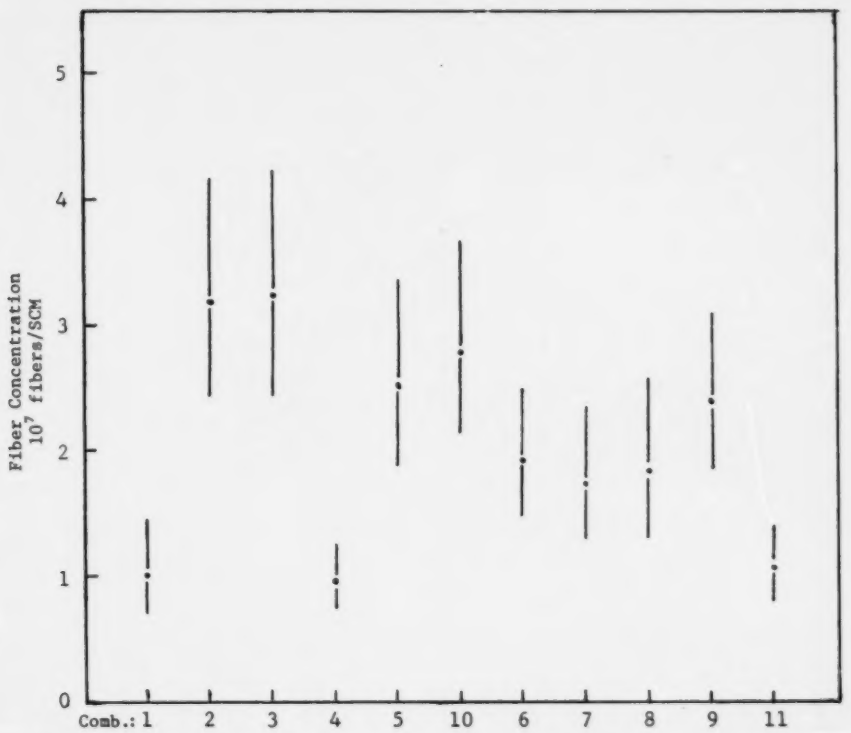

Figure 1. Output geometric mean fiber concentrations with 90 percent confidence intervals for all combinations.

$$Y2^* = b_0 + b_1(X1L) + b_2(X2L) + b_3(X3L) + b_4(X1Q) + b_5(X2Q) + b_6(X3Q) \; [+ b_7(Z2)]$$

$Y2^*$, the dependent variable, is the predicted value of mean log fiber concentration as a function of the expression on the right. X1L, X1Q, etc., are the candidate independent variables defined in Table 4. They represent the linear and quadratic effects on mean log fiber concentration of varying the shake period, duration, and amplitude. Z2 is a candidate covariate, defined in Table 4, that permits the effect of the magnitude of the baghouse input stream on the output fiber concentration to be incorporated into the performance equation. The brackets enclosing the covariate term in the model equation indicate that model equations were constructed with and without the covariate.

The orthagonal coding used to identify the data input is given in Table 9.

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TABLE 9. CANDIDATE INDEPENDENT VARIABLES FOR EQUATION CONSTRUCTION

Symbol	Coded Values	Effect Represented
X1L	-1, 0, +1	Linear effect of log shake period
X1Q	+1, -2, +1	Quadratic effect of log shake period
X2L	-1, 0, +1	Linear effect of log shake duration
X2Q	+1, -2, +1	Quadratic effect of log shake duration
X3L	-1, 0, +1	Linear effect of log shake amplitude
X3Q	+1, -2, +1	Quadratic effect of log shake amplitude

Method of Equation Construction--

The coefficients of the model, i.e., b_0 (the constant term), b_1, etc., were computed from the test data by the method of least squares.

A stepwise procedure was employed in equation construction, and only those candidate variables of the model that were found to have effects of statistical significance at the 0.10 probability level on the predicted value dependent variable were incorporated into the regression equations. The IITRI stepwise regression program, NEW02R, was used to perform the computations on the IBM 1108 computer.

Two performance equations were developed using data from combinations 1-10. Equation 4, generated without the covariate term, is:

$$Y2^* = 0.6750 + 0.0702\ (X1Q) + 0.3517\ (X2L) - 0.1214\ (X2Q) - 0.1112\ (X3Q) \quad (4)$$

The covariate Z2 was permitted to enter Equation 5:

$$Y2^* = -0.6341 + 0.0694\ (X1Q) + 0.3219\ (X2L) - 0.1220\ (X2Q) - 0.0759\ (X3Q) + 0.2997\ (Z2) \quad (5)$$

Conclusions Based on the Equations--

Equation 5 has one more predictive variable than Equation 4, the baghouse inlet load, and shows a decrease of the residual standard deviation of Y2 from 0.4735 to 0.4481 and an increase of R^2 from 40.7 to 47.6 percent.

The most significant variables representing the controlled factors of the experiment design (i.e., those variables with the smallest chance probabilities, P, see Tables 6 and 7) refer to the duration of the shake cycle. The indicated net effect of increasing the duration of the shake cycle from 10 to 20 to 40 sec, under the conditions of the plant experiment, is an increase and then a leveling off or decrease of the asbestos output concentra-

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tion as shown in Figure 2.

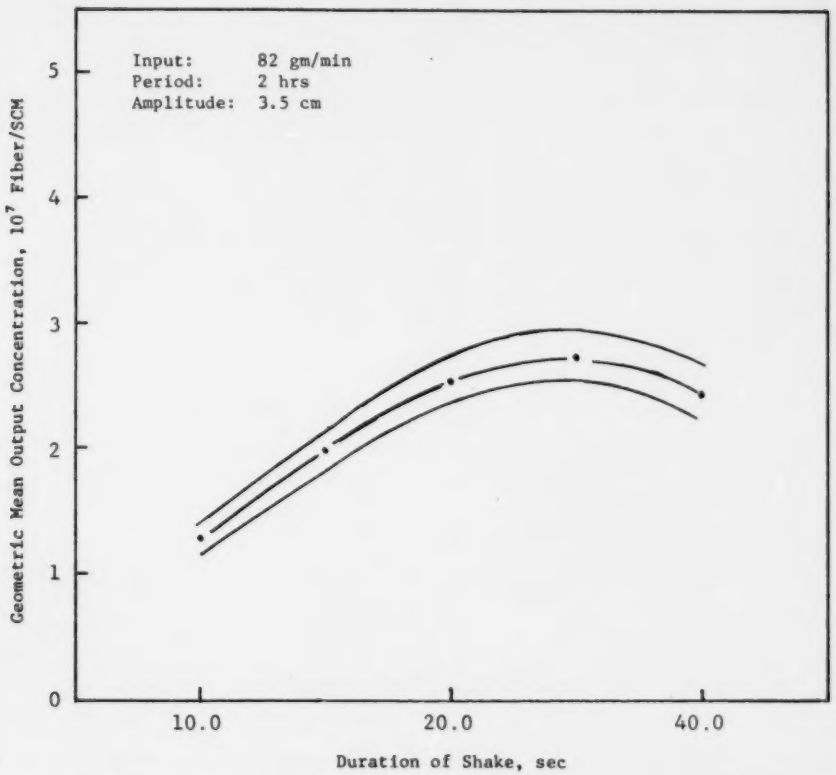

Figure 2. Shake duration vs. baghouse output--based on Equation 2 with 90% confidence band.

The effect of varying the period between shakes is a minimization of the output fiber concentration at roughly the intermediate period tested, i.e., 2 hours. This effect is shown in Figure 3. More detailed information on the two equations is given in Tables 10 and 11, including the standard errors of the regression coefficients, the variance ratios, the probabilities of chance occurrence due to the residual scatter of the data, the residual degrees of freedom and standard deviation, and the R^2 value. The R^2 value is the proportion of the raw variation of the dependent variable (sum of squared deviations from the mean) that is accounted for by the predictive variables in the best fit equation.

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TABLE 10. DETAILED INFORMATION ON EQUATION 4

Predictive Variable	Coefficient b	Standard Error of b	Variance Ratio, F	Chance Probability, P
CONSTANT TERM				
XO = 1	0.6750			
INDEPENDENT VARIABLES				
X1Q	0.0702	.0357	3.87	.05
X2L	0.3517	.0663	28.14	<.001
X2Q	-0.1214	.0378	10.34	.002
X3Q	-0.1112	.0364	9.31	.003

Dependent variable: Y2*, Ln (10^7 fibers/SCM air)
Data base: test combinations 1-10
Number of observations (samples): 82
Number of terms in equation: 5
Candidate variables excluded: (linear effect of shake period and shake amplitude)
Residual degrees of freedom: 77
Residual standard deviation of Y2: 0.4735
R^2 value: 40.7%

TABLE 11. DETAILED INFORMATION ON EQUATION 5

Predictive Variable	Coefficient b	Standard Error of b	Variance Ratio, F	Chance Probability, P
CONSTANT TERM				
XO =1	-0.6341			
INDEPENDENT VARIABLES				
X1Q	0.0694	.0338	4.22	.04
X2L	0.3219	.0634	25.74	<.001
X2Q	-0.1220	.0357	11.65	.001
X3Q	-0.0759	.0363	4.38	.04
COVARIATE				
Z2	0.2997	.0949	9.98	.002

Dependent variable: Y2*, Ln (10^7 fibers/SCM air)
Data base: test combinations 1-10
Number of observations (samples): 82
Number of terms in equation: 6
Candidate variables excluded: Linear effects of shake period and shake amplitude
Residual degrees of freedom: 76
Residual standard deviation of Y2: 0.4481
R^2 value: 47.6%

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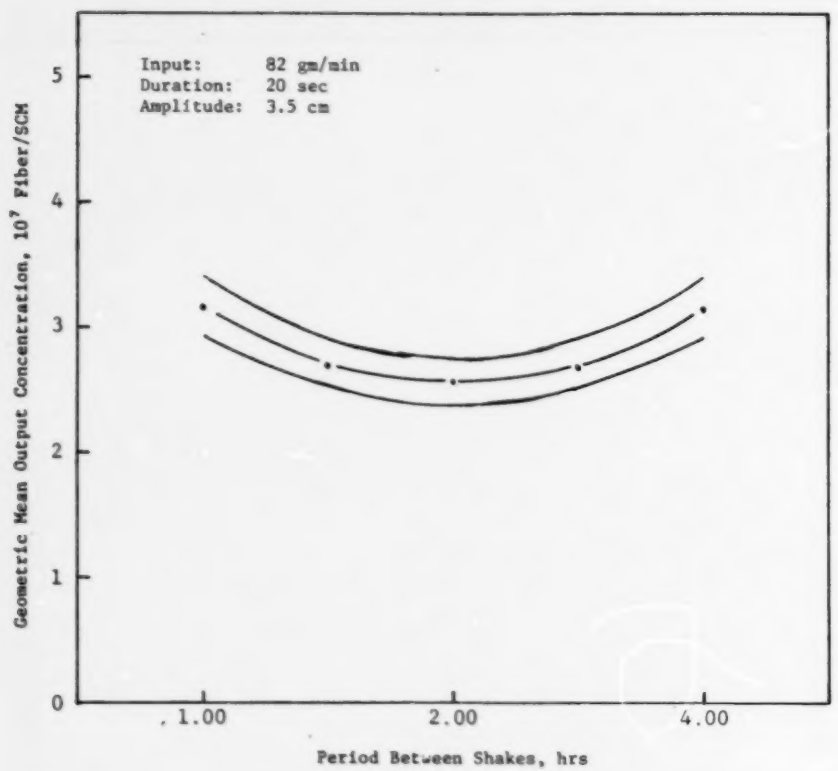

Figure 3. Period between shakes vs. baghouse output--based on Equation 2 with 90% confidence band.

Total Correlations--

The total correlations between the dependent variable Y2 and the five predictive variables that are in Equation 4 and/or 5 are given in Table 12. All these correlations, except that between Y2 and X1Q, are significantly different from zero at the 0.10 probability level. The number of degrees of freedom is uniformly n = 80, two less than the number of pairs of values from which each correlation coefficient, r, was computed. Of particular interest is the fact that the sign of the raw correlation and the sign of the corresponding regression coefficient in either equation are the same. This lends support to the validity of the effects represented in the equations.

The effect of varying the shake amplitude is shown in Figure 4. The two extremes tested, 1.75 and 7.00 cm, tend to result in somewhat lower fiber output concentrations than the intermediate level, 3.50 cm.

The summary of major conclusions based on linear regression analysis of the primary data base were:

- Two of the selected parameters, shake duration and shake amplitude showed the maximums in their output curves. The

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TABLE 12. TOTAL CORRELATIONS BETWEEN PREDICTIVE VARIABLES AND THE DEPENDENT VARIABLE Y2

Variable Pair	Degrees of Freedom, n	Correlation Coefficient, r
Y2, X1Q	80	+0.141
Y2, X2L	80	+0.449
Y2, X2Q	80	-0.295
Y2, X3Q	80	-0.309
Y2, Z2	80	+0.407

* A correlation coefficient of $\pm$0.183 or greater is significant at the 0.10 probability level for n = 80.

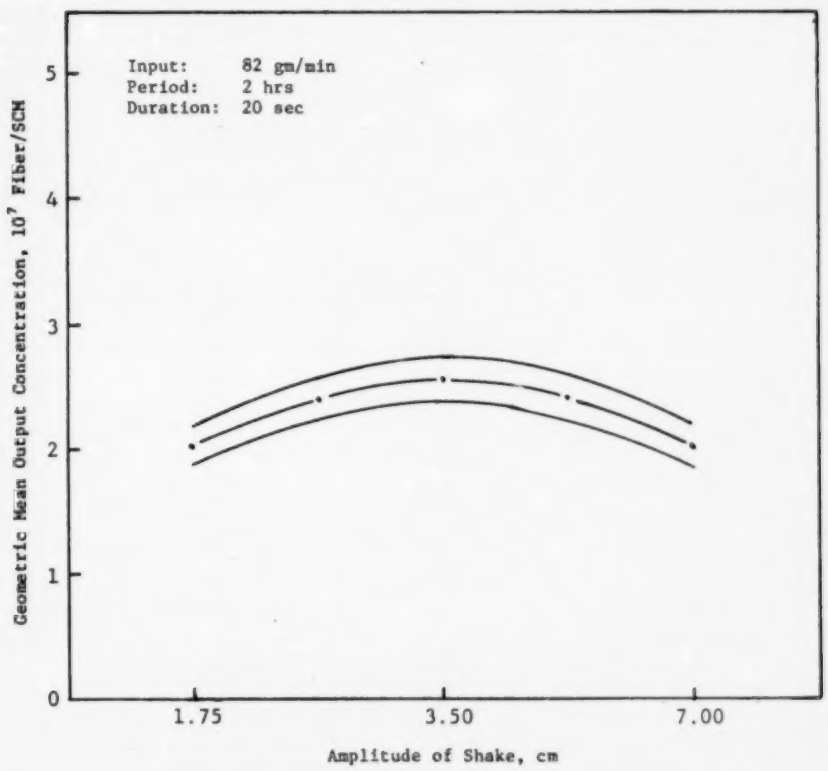

Figure 4. Shake amplitude vs. baghouse output-- based on Equation 2 with 90% confidence band.

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existence of a maximum rather than a minimum implies either that there is no optimum, or that the optimum is outside the experimental range of the parameters.

- The shake period showed a minimum at the midpoint of the values studied.
- A positive correlation between mass loading of the baghouse and the output concentration has been obtained.
- The lowest output concentration obtained is equivalent to the baseline concentration. The baseline conditions are outside the range of parameters studied.
- All values of concentration measured were at approximately 10×10^6 to 50×10^6 fibers/SCM. This is equivalent to 10-50 fibers/cc in the baghouse outlet. Also, since about 10% of the total fibers are above 5 μm in length, the OSHA concentrations measured in the baghouse plenum would be 1-5 fibers/cc.

There were two conclusions which required additonal study. The first was that a previous study had showed, by similar statistical analysis, that the type of waste was more significant than the mass loading. The second was that the baseline data, obtained at a 12-hour shake period and 300-sec shake duration, showed an output concentration equivalent to the lowest obtained in the experimental design. The shake period and shake duration were greater than those studied, while the shake smplitude was identical to the longest amplitude used in the design.

The apparent contradiction between a well-controlled pilot study showing the type of asbestos waste more significant than the mass load and the field demonstration showing some degree of correlation with mass loading was addressed first. Inspection of values from Table 13 which shows the outlet fiber concentration, the overall mass loading, the cumulative load[illegible]rom the sources working on asbestos-containing materials, and the split between the "finish" and "rough" working areas, showed little if any pattern. Attempts to correlate the use of particular materials and the loading in any given duct also gave "positive" correlations, but no specific pattern developed. Insufficient data was available to use statistics to sort out the effects of the uncontrolled variables of type of waste and the particular operations in the plant.

Ducts #1 and #2 were associated with the two primary cutters, while duct #3 was used intermittently for a small saw, drilling and routine tasks, and duct #4 was associated with final hole drilling, sanding in preparation for painting and small part production. It was not practical with the single person present to maintain records on production rate and the time of specific operation during each test. Neither was it within the scope of this effort to characterize the types of waste in each inlet duct as to size distribution or inlet fiber loading.

Thus, the tentative conclusion that mass loading alone was responsible for the improved correlation obtained by including mass loading as a parameter

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TABLE 13. SUMMARY OF LOADING DATA OBTAINED DURING PHASE I

Test No.	Comb. No.	Output	Input			
		Million Fibers/SCM fibers/CC	Total Mass Rate gm/min	Asbestos Containing gm/min	Process Type	
					rough	finish
1-1	2	35.3				
1-2		37.0	261	261	90%	10%
1-3		15.1	125	125	30	70
1-4		47.4	136	132	88	12
1-5		15.6	140	138	40	60
1-6		31.2	144	144	70	30
1-7		57.8	105	105	70	30
1-8	2	40.0	89	89	60	40
2-9	7	12.6	87	85	90	10
2-10		17.0	222	221	85	15
2-11		18.7	107	106	85	15
2-12		26.5	111	111	85	15
2-13		23.2	78	78	85	15
2-14		19.9	146	146	85	15
2-15		8.5	131	130	90	10
2-16	7	21.3	152	152	90	10
3-17	6	12.5	121	121	95	5
3-18		27.3	187	187	99	1
3-19		23.3	183	180	65	35
3-20		21.7	125	125	95	5
3-21		38.7	135	135	95	5
3-22		14.5	154	153	90	10
3-23		12.7	63	63	85	15
3-24		15.9	48	46	50	50
3-25		26.7	37	36	70	30
3-26	6	14.0	77	77	85	15
4-27	4	16.1	124	124	80	20
4-28		7.5	56	56	55	45
4-29		5.8	69	69	90	10
4-30		9.8	46	45	70	30
4-31		11.1	75	75	95	5
4-32		9.4	51	49	95	5
4-33		15.7	99	99	95	5
4-34		9.2	68	68	70	30
4-35		7.8	42	40	95	5
4-36	4	9.6	75	73	80	20

(continued)

TABLE 13. (continued)

Test No.	Comb. No.	Output	Input			
		Million Fibers/SCM fibers/CC	Total Mass Rate gm/min	Asbestos Containing gm/min	Process Type	
					rough	finish
5-37	9	13.1	79	79	95%	5%
5-38		25.6	59	59	90	10
5-39		12.8	22	18	85	15
5-40		26.3	56	56	75	25
5-41		68.5	53	52	70	30
5-42		30.4	82	82	80	20
5-43		14.2	81	80	88	12
5-44		14.6	90	90	90	10
5-45		25.9	55	55	90	10
5-46	9	54.0	33	33	80	20
6-86	5	13.9	48	48	95	5
6-87		45.6	64	64	85	15
6-88		35.4	60	59	70	30
6-89		33.8	105	105	50	50
6-90		35.3	109	108	85	15
6-91		27.7	97	97	30	70
6-92		21.4	70	70	95	5
6-93	5	10.7	43	43	50	50
7-47	1	28.6	81	81	90	10
7-48		8.3	48	47	95	5
7-49		4.4	42	42	95	5
7-51		7.5	14	12	90	10
7-52	1	13.3	23	23	90	10
8-53	8	32.8	90	90	95	5
8-54		18.8	117	117	95	5
8-55		11.7	33	33	75	25
8-56		34.9	55	55	80	20
8-57		27.1	59	59	95	5
8-58	3	5.9	29	28	95	5
9-68	3	23.3	75	73	90	10
9-69		21.0	62	62	95	5
9-70		20.5	99	98	75	25
9-71		49.8	126	126	85	15
9-72		35.1	174	174	75	25
9-73		43.7	139	138	60	40
9-74		35.9	194	193	65	35

(continued)

TABLE 13. (continued)

Test No.	Comb. No.	Output	Input			
		Million Fibers/SCM fibers/CC	Total Mass Rate gm/min	Asbestos Containing gm/min	Process Type	
					rough	finish
9-75		21.3	94	94	95%	5%
9-76	3	64.9	184	184	80	20
10-77	10	24.6	76	75	60	40
10-78		30.4	147	146	20	80
10-79		32.5	61	59	80	20
10-80		35.9	116	116	60	40
10-81		29.0	115	114	85	15
10-82		22.9	74	72	30	70
10-83		15.6	123	122	85	15
10-84		36.4	150	150	70	30
10-85	10	32.3	51	51	95	5
11-59		36.4	48	46	90	10
11-60		13.3	46	45	50	50
11-61		14.1	40	40	80	20
11-62		19.5	89	89	75	25
11-63		8.6	39	39	80	20
11-64		6.2	45	44	80	20
11-65		4.3	32	32	90	10
11-66		7.2	45	43	95	5
11-67		9.6	58	58	95	5

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may reflect waste type and/or processing changes. The maxima in the shake duration and the shake amplitude are difficult to explain, and the reason must lie in the development of the cake on the inside of the bags. It is apparent that various combinations of shake amplitudes and durations, in combination with various site specific parameters, lead to a more porous or open cake structure, although the pressure drop data presented in Table 14 shows the mean pressure drop as a complex function of the conditions of the test. The pressure drop itself does not correlate with the fiber output. The conclusion most consistent with the data appears to be that disturbance of the cake is best to be avoided since the 5 lowest tests all share either very mild shake conditions or long intervals between shakes.

TABLE 14. COMPARISON OF BAGHOUSE PRESSURE DROP TO EXPERIMENTAL PARAMETERS AND FIBER OUTPUT CONCENTRATION

Order Test No.	Comb. No.	Mean ΔP ("H_2O)	Operating Parameter Values (hrs, sec, cm)	Geometric Mean Fiber Concentration (million fibers/SCM)
1	2	1.33	1, 20, 1.75	31.8
2	7	1.36	4, 10, 3.5	17.5
3	6	1.34	2, 40, 7.0	19.3
4	4	1.08	2, 10, 1.75	9.7
5	9	1.04	4, 40, 1.75	24.2
6	5	1.00	2, 20, 3.5	25.3
7	1	0.66	1, 10, 7.0	10.1
8	8	0.90	4, 20, 7.0	18.5
9	3	1.30	1, 40, 3.5	32.3
10	10	0.79	2, 20, 3.5	28.0
11	11	1.27	12, 300, 7.0	10.9
12	12	1.37	6, 32, 7	6.1
13	13	0.93	6, 108, 7	5.8
14	14	1.01	12, 230, 7	7.2

Results of Additional Tests

The baseline data indicated that longer periods between shakes and extended shake intervals could also produce a high degree of fiber emission control. Additional tests to establish if this was correct were recommended and performed. Three additional tests were performed with parameters of:

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3/8"

PAGE NUMBER
EPA-287 (Cln.) (4-76)

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Test #	Combination #	Shake Interval (hrs)	Shake Duration (sec)	Shake Amplitude (cm)
12	12	6	32	7
13	13	6	108	7
14	14	12	230	7

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These three tests were intended to resolve two questions:

- Does output fiber concentration level off beyond the 40 sec shake duration?
- Does output fiber concentration decline at longer intervals between shakes?

These tests were recommended on the basis of test 11 which, while strongly indicative, had not been performed using the established procedures of new bags conditioned at the conditions of testing.

The results of the tests, the geometric means of which are presented in Table 15, showed that shake duration is not highly significant, although a trend toward higher (but not highly significant) fiber output concentrations exists as shake duration passes two minutes (120 sec) in length. The interval between shakes also showed no great influence on outlet concentration beyond a 6-hour interval where the control was equivalent to the best values obtained previously.

As seen in Table 15, the geometric mean fiber concentrations varied very little and the fiber concentration was relatively stable for the runs made.

The inlet fiber loading was, in general, similar to the loading in the earlier tests. However, one portion of the plant had been converted to a non-asbestos (stainless steel) work area. In general, a relatively small proportion of the mass loading came from this area (less than 10%) and the loading can be considered comparable.

From the data taken, the conclusions are:

- Extending the length of the period between shakes is beneficial.
- For some applications, the pressure drop is not significantly affected by extended shake interval.
- Automation of the shake cycle leads to better performance of the baghouse.*
- Shake duration at extended intervals between shakes is not a significant parameter.
- The duration of the shake cycle seems to be the most

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* Personal communication--Plant personnel.

3/8"
BOTTOM OF IMAGE AREA, OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS

PAGE NUMBER
EPA-287 (Cin.) (4-76)

important parameter, both from statistical and observed standpoints.

- Interactions between variables are important, but cannot be computed from the partial factorial experiment. The interactions make formulation of a design equation impractical.

TABLE 15. INLET LOADING AND OUTLET FIBER CONCENTRATION: PHASE II

Sample No.	Inlet Loading gm/m^3	Fiber Concentration $fibers/m^3$	Geometric Mean Fiber Concentration $fibers/m^3$
12-1	21	6.85×10^6	
12-2	110	9.72×10^6	
12-3	78	7.03×10^6	
12-4	143	11.68×10^6	
12-5	34	1.23×10^6	
12-6	93	0.96×10^6	
12-7	87	6.68×10^6	
12-8	61	17.85×10^6	
12-9	211	6.03×10^6	
12-10	131	14.12×10^6	
			6.05×10^6
13-1	90	2.35×10^6	
13-2	44	4.98×10^6	
13-3	132	4.30×10^6	
13-4	141	3.00×10^6	
13-5	45	5.49×10^6	
13-6	79	8.42×10^6	
13-7	56	9.50×10^6	
13-8	50	3.75×10^6	
13-9	108	6.83×10^6	
13-10	120	24.63×10^6	
			5.78×10^6
14-1	64	2.99×10^6	
14-2	65	13.91×10^6	
14-3	40	8.49×10^6	
14-4	65	8.85×10^6	
14-5	58	11.21×10^6	
14-6	61	8.20×10^6	
14-7	58	7.68×10^6	
14-8	27	5.18×10^6	
14-9	46	5.10×10^6	
14-10	50	6.78×10^6	
			7.24×10^6

APPENDIX A

PLANT OPERATING AND SAMPLE QUALITY ASSURANCE DATA

Appendix A contains five tables. Table A-1 shows the data collected on each sampling run from the EPA Method 5 sampling train used. This data was used to compute the percent isokinetic and the SCM of air measured. The olume sampled was used in the computation of the fiber concentration shown in the body of the report. Table A-1 is in English units to be compatible with the instrumentation used.

Table A-2 contains the data obtained from the inlet ducts. The samples were numbered serially during the pre-weighing procedure, and were used on ducts 1, 2, 3, and 4 in sequence. The flow through each filter was controlled at near-isokinetic conditions by the sampling nozzle size and the selection of a critical orifice for flow control.

Tables A-3 and A-4 contain the output data from the electron microscopy analysis. The fiber concentration obtained from each analysis is shown in Table A-3, while the cumulative frequency distribution is shown in Table A-4 by sample for the first series of experiments and in Table A-5 for the second series of experiments.

TABLE A-1. ISOKINETIC SAMPLING DATA AND CALCULATIONS

Test No. - Sample No.	Sampling Time (min.)	Avg. Differential Stack Pressure $\overline{\Delta P}$ (in. H_2O)	Avg. Square Roots ΔP $\overline{\sqrt{\Delta P}}$ (in. $H_2O)^{1/2}$	Avg. Differential Orifice Pressure $\overline{\Delta h}$ (in. H_2O)	Barometric Pressure P_b (in. Hg)	Avg. Stack Temperature $\overline{T_s}$ (^oR)	Avg. Meter Temperature $\overline{T_m}$ (^oR)	Volume of Gas Metered V_m ($ft.^3$)	Percent Isokinetic %I
1-1	141	.229	.478	2.66	29.84	532.1	538.8	323.165	102
1-2	180	.233	.483	2.66	29.84	542.0	549.6	418.107	101
1-3	180	.229	.478	2.66	30.03	532.7	540.0	414.434	103
1-4	180	.235	.485	2.65	30.03	546.3	551.3	417.288	101
1-5	180	.231	.480	2.69	30.02	531.6	537.8	418.516	104
1-6	180	.230	.480	2.69	30.02	535.8	546.5	420.389	103
1-7	120	.230	.480	2.67	30.21	523.6	532.9	276.329	103
1-8	90	.230	.480	2.70	30.21	534.0	548.3	210.170	103
2-9	180	.244	.494	2.84	29.79	531.1	542.1	427.830	102
2-10	180	.265	.515	3.07	29.79	540.7	550.0	445.813	101
2-11	180	.260	.510	3.03	29.66	533.6	545.1	443.176	102
2-12	180	.260	.510	3.06	29.66	533.4	546.1	445.983	102
2-13	180	.251	.501	2.97	29.73	529.6	543.1	438.685	103
2-14	180	.250	.500	2.93	29.73	536.9	548.1	435.656	106
2-15	180	.247	.497	2.92	30.19	530.2	544.2	433.237	103
2-16	180	.268	.517	3.12	30.19	542.4	554.4	448.802	102
3-17	180	.260	.510	3.08	30.52	535.2	547.4	440.922	102
3-18	180	.260	.510	3.00	30.52	543.9	551.8	439.078	102
3-19	180	.260	.510	3.06	30.51	537.8	549.8	442.153	102
3-20	180	.260	.510	3.01	30.51	545.2	550.0	439.473	102
3-21	180	.287	.536	3.42	30.39	537.1	555.0	467.373	102
3-22	180	.260	.510	3.00	30.39	546.1	551.3	439.964	102
3-23	180	.272	.521	3.23	30.37	534.6	553.5	455.228	102
3-24	180	.270	.520	3.15	30.37	541.6	553.6	450.105	102
3-25	180	.280	.529	3.30	30.32	538.6	554.9	461.362	102
3-26	171	.280	.529	3.29	30.32	543.2	557.3	437.788	102
4-27	180	.300	.548	3.57	30.17	526.6	542.6	475.658	102
4-28	180	.300	.548	3.58	30.17	535.5	553.4	478.688	102
4-29	180	.280	.529	3.29	30.14	530.6	545.1	458.400	102
4-30	180	.280	.529	3.26	30.14	539.8	548.9	458.561	102
4-31	180	.280	.529	3.31	29.97	535.6	553.0	462.380	102
4-32	180	.280	.529	3.30	29.97	538.1	551.0	462.696	102
4-33	180	.280	.529	3.33	29.64	535.1	552.6	466.390	102
4-34	180	.280	.529	3.31	29.64	537.4	550.9	466.000	102
4-35	180	.280	.529	3.32	29.86	530.3	546.8	462.452	102
4-36	180	.280	.529	3.30	29.86	538.1	554.2	462.494	101

(continued)

TABLE A-1. (continued)

Test No. - Sample No.	Sampling Time (min.)	Avg. Differential Stack Pressure $\overline{\Delta P}$ (in. H_2O)	Avg. Square Roots ΔP $\sqrt{\Delta P}$ (in. $H_2O)^{1/2}$	Avg. Differential Orifice Pressure $\overline{\Delta h}$ (in. H_2O)	Barometric Pressure P_b (in. Hg)	Avg. Stack Temperature $\overline{T_s}$ (°R)	Avg. Meter Temperature $\overline{T_m}$ (°R)	Volume of Gas Metered V_m (ft.^{3})	Percent Isokinetic %I
5-37	120	.240	.490	2.87	30.36	524.1	539.5	285.326	103
5-38	120	.240	.490	2.84	30.36	531.6	544.2	285.731	103
5-39	120	.240	.490	2.88	29.72	523.6	545.5	290.117	103
5-40	120	.240	.490	2.90	29.72	528.7	554.1	292.174	103
5-41	120	.220	.469	2.60	29.90	522.6	540.3	277.318	104
5-42	120	.228	.478	2.72	29.90	533.8	552.1	283.504	103
5-43	120	.228	.478	2.68	30.03	523.3	532.7	278.339	104
5-44	120	.230	.480	2.70	30.03	531.1	538.1	280.736	104
5-45	120	.218	.466	2.57	29.27	523.8	536.3	277.881	105
5-46	120	.230	.480	2.70	29.27	535.6	544.9	283.913	103
7-47	120	.243	.492	2.83	30.29	516.4	524.4	282.128	104
7-48	120	.260	.510	3.08	30.29	527.0	543.1	296.097	103
7-49	120	.195	.441	2.30	30.51	522.0	532.4	258.472	105
7-50	PLANT BREAKDOWN - RUINED SAMPLE								
7-51	101.65	.221	.470	2.62	29.81	523.8	538.2	236.187	105
7-52	120	.230	.480	2.70	30.35	516.6	530.0	278.396	104
8-53	120	.183	.428	2.14	29.79	515.4	525.0	252.986	106
8-54	120	.206	.454	2.41	30.22	521.6	531.2	264.688	105
8-55	120	.215	.464	2.55	30.22	529.3	543.6	273.340	104
8-56	120	.203	.450	2.39	30.14	520.6	533.9	264.675	105
8-57	120	.220	.469	2.60	30.14	529.2	544.4	276.967	104
8-58	120	.175	.418	2.04	30.03	517.0	526.1	241.700	104
11-59	120	.210	.458	2.49	30.17	526.5	537.1	268.576	104
11-60	120	.226	.475	2.73	30.17	529.5	552.8	282.418	103
11-61	120	.212	.460	2.48	29.93	521.3	534.0	268.935	104
11-62	120	.227	.476	2.73	29.93	530.3	553.7	284.085	103
11-63	120	.190	.436	2.20	29.78	521.1	524.6	254.531	105
11-64	120	.210	.458	2.49	29.78	531.2	542.9	273.142	105
11-65	120	.190	.436	2.21	29.78	522.3	530.6	256.500	105
11-66	120	.210	.458	2.50	29.78	534.8	551.5	274.100	104
11-67	120	.193	.440	2.25	29.74	520.0	528.8	258.394	105

(continued)

TABLE A-1. (continued)

Test No. - Sample No.	Sampling Time (min.)	Avg. Differential Stack Pressure ΔP (in.H_2O)	Avg. Square Roots ΔP $\sqrt{\Delta P}$ (in.$H_2O)^{\frac{1}{2}}$	Avg. Differential Orifice Pressure Δh (in.H_2O)	Barometric Pressure P_b (in.Hg)	Avg. Stack Temperature T_s (^oR)	Avg. Meter Temperature T_m (^oR)	Volume of Gas Metered V_m (ft.^{3})	Percent Isokinetic %I
9-68	120	.256	.506	2.98	30.35	533.5	541.7	292.524	103
9-69	120	.260	.510	3.09	30.35	534.4	552.4	298.111	102
9-70	120	.238	.488	2.82	29.86	528.2	539.6	285.250	103
9-71	120	.247	.496	2.94	29.86	532.3	545.7	293.460	104
9-72	120	.257	.507	2.98	29.86	537.2	542.5	293.886	103
9-73	120	.260	.510	3.01	29.86	541.7	550.2	295.777	102
9-74	120	.230	.480	2.68	30.08	530.7	536.6	278.428	104
9-75	120	.230	.480	2.70	30.08	530.8	541.2	281.190	104
9-76	120	.218	.466	2.52	29.95	526.5	525.7	270.452	105
10-77	120	.270	.520	3.19	29.67	532.1	545.0	304.506	103
10-78	120	.283	.532	3.40	29.67	534.8	554.7	315.324	102
10-79	120	.270	.520	3.18	29.91	534.4	549.2	302.920	102
10-80	120	.270	.520	3.12	29.91	545.3	549.3	300.520	102
10-81	120	.270	.520	3.16	29.95	538.0	548.1	301.264	102
10-82	120	.270	.520	3.13	29.95	545.6	552.2	301.233	102
10-83	120	.269	.519	3.15	30.21	530.8	542.6	298.949	102
10-84	120	.270	.520	3.09	30.21	545.3	546.0	297.357	102
10-85	120	.250	.500	2.95	30.15	529.7	541.2	289.973	103
6-86	120	.275	.524	3.32	30.07	524.3	548.4	308.347	103
6-87	120	.270	.520	3.14	30.07	538.8	548.5	301.081	102
6-88	120	.250	.500	2.99	29.75	529.0	544.3	293.931	103
6-89	120	.260	.510	3.09	29.75	536.8	553.4	301.580	103
6-90	120	.250	.500	2.95	29.78	532.7	542.3	291.059	103
6-91	120	.260	.510	3.01	29.78	545.3	554.5	295.455	101
6-92	120	.250	.500	2.97	29.74	532.8	548.2	293.035	102
6-93	120	.260	.510	3.06	29.74	544.8	556.7	300.468	102

(continued)

TABLE A-1. (continued)

Test No. - Sample No.	Sampling Time (min.)	Avg. Differential Stack Pressure $\overline{\Delta P}$ (in. H_2O)	Avg. Square Roots ΔP $\overline{\sqrt{\Delta P}}$ (in. $H_2O)^{1/2}$	Avg. Differential Orifice Pressure $\overline{\Delta h}$ (in. H_2O)	Barometric Pressure P_b (in. Hg)	Avg. Stack Temperature $\overline{T_s}$ (^oR)	Avg. Meter Temperature $\overline{T_m}$ (^oR)	Volume of Gas Metered V_m ($ft.^3$)	Percent Isokinetic %I
12-1	120	0.302	0.549	2.82	30.20	542.1	547.4	297.8	96
12-2	120	0.243	0.493	2.52	30.16	540.9	550.68	281.7	102
12-3	120	0.287	0.536	3.14	30.14	531.9	539.6	309.0	103
12-4	120	0.285	0.534	3.09	20.13	536.3	546.1	318.2	106
12-5	120	0.278	0.527	3.00	30.04	532.7	539.8	305.1	103
12-6	120	0.273	0.523	2.92	30.05	533.7	539.8	302.4	103
12-7	120	0.282	0.531	3.10	20.01	536.6	542.3	309.5	104
12-8	120	0.285	0.534	3.10	29.97	551.5	556.7	312.0	103
12-9	120	0.275	0.525	3.0	29.93	543.6	547.8	306.5	103
12-10	120	0.271	0.521	2.93	29.91	548.8	554.4	305.4	103
13-1	120	0.264	0.514	2.92	30.20	542.1	547.4	301.7	104
13-2	120	0.279	0.528	3.04	30.18	545.17	554.4	311.1	104
13-3	120	0.272	0.522	3.02	30.22	540.1	546.1	307.0	105
13-4	120	0.285	0.534	3.15	30.15	546.1	556.3	315.5	104
13-5	120	0.269	0.519	2.91	30.08	543.8	549.0	302.1	103
13-6	120	0.265	0.515	2.88	30.04	548.0	556.4	304.0	103
13-7	120	0.256	0.506	2.83	29.91	540.5	547.0	298.7	104
13-8	120	0.254	0.504	2.80	29.85	546.5	555.0	301.7	105
13-9	120	0.254	0.504	2.80	29.89	540.2	547.7	299.3	105
13-10	120	0.259	0.509	2.86	29.89	547.2	552.0	301.9	104
14-1	120	0.284	0.533	3.11	29.95	542.4	549.7	314.7	104
14-2	120	0.287	0.536	3.12	29.93	552.7	560.3	316.2	103
14-3	120	0.267	0.517	2.96	30.09	534.1	542.4	304.2	105
14-4	120	0.275	0.524	3.06	30.08	540.1	552.4	311.2	104
14-5	120	0.273	0.522	2.99	29.89	541.0	546.4	306.9	104
14-6	120	0.285	0.534	3.10	20.90	550.0	558.4	314.6	103
14-7	120	0.274	0.524	3.06	30.09	538.3	546.7	310.5	105
14-8	120	0.279	0.528	3.09	30.14	546.8	557.4	312.8	104
14-9	120	0.262	0.512	2.95	29.98	541.7	547.9	308.2	106
14-10	120	0.272	0.521	3.06	29.90	550.2	555.3	313.6	106

TABLE A-2. PLANT EMISSION RATE DATA

Inlet Filter Number	Date Taken	Corresponding Outlet Sample	Inlet Material Weight (gm)	Sample Time (min)	Sample Flow Rate (ℓ/min)	Inlet Concentration (mg/ℓ)	Percent* Total Flow (%)	Weighted Average Concentration (mg/ℓ)	Total Plant Emission Rate (gm/min)
1	10/04/77	1-1	-	141	-	-	22		
2	"	1-1	-	141	-	-	43		
3	"	1-1	-	141	-	-	15		
4	"	1-1	-	141	-	-	20	POWER	FAILURE
5	"	1-2	1.0922	66	4.9	3.377	22		
6	"	1-2	0.0047	66	15.0	0.005	43		
7	"	1-2	0.0014	66	15.0	0.001	15		
8	"	1-2	0.1008	66	4.9	0.312	20	0.808	261.
9	10/05/77	1-3	0.1042	62	4.9	0.343	22		
10	"	1-3	0.3246	132	15.0	0.164	43		
11	"	1-3	1.1876	91	15.0	0.870	15		
12	"	1-3	0.3331	121	4.9	0.562	20	0.389	126.
13	"	1-4	0.3693	60	4.9	1.256	22		
14	"	1-4	0.3514	120	15.0	0.195	43		
15	"	1-4	0.1297	120	15.0	0.072	15		
16	"	1-4	0.1477	120	4.9	0.251	20	0.421	136.
17	10/06/77	1-5	0.3957	130	4.9	0.621	22		
18	"	1-5	0.1836	150	15.0	0.082	43		
19	"	1-5	0.0524	150	15.0	0.023	15		
20	"	1-5	0.3895	63	4.9	1.262	20	0.428	138.
21	"	1-6	0.7518	91	4.9	1.686	22		
22	"	1-6	0.0965	150	15.0	0.043	43		
23	"	1-6	0.0034	180	15.0	0.001	15		
24	"	1-6	0.2422	180	4.9	0.275	20	0.445	144.
25	10/07/77	1-7	0.2606	61	4.9	0.872	22		
26	"	1-7	0.0710	61	15.0	0.078	43		
27	"	1-7	0.0045	60	15.0	0.005	15		
28	"	1-7	0.1436	60	4.9	0.488	20	0.324	105.
29	"	1-8	0.2161	60	4.9	0.735	22		
30	"	1-8	0.0738	60	15.0	0.082	43		
31	"	1-8	0.0042	60	15.0	0.005	15		
32	"	1-8	0.1141	60	4.9	0.388	20	0.275	88.9

(continued)

* Percent of total flow going into the baghouse.

TABLE A-2. (continued)

Inlet Filter Number	Date Taken	Corresponding Outlet Sample	Inlet Material Weight (gm)	Sample Time (min)	Sample Flow Rate (ℓ/min)	Inlet Concentration (mg/ℓ)	Percent* Total Flow (%)	Weighted Average Concentration (mg/ℓ)	Total Plant Emission Rate (gm/min)
33	10/18/77	2-9	0.2553	60	4.9	0.868	22		
34	"	2-9	0.2511	120	15.0	0.140	43		
35	"	2-9	0.1096	150	15.0	0.049	15		
36	"	2-9	0.0469	150	4.9	0.064	20	0.271	87.6
37	"	2-10	0.2952	60	4.9	1.004	22		
38	"	2-10	0.9108	70	15.0	0.867	43		
39	"	2-10	0.0102	121	15.0	0.006	15		
40	"	2-10	0.2745	121	4.9	0.463	20	0.687	222.
41	10/19/77	2-11	0.3362	60	4.9	1.144	22		
42	"	2-11	0.1574	130	15.0	0.081	43		
43	"	2-11	0.0478	130	15.0	0.025	15		
44	"	2-11	0.0904	90	4.9	0.205	20	0.331	107.
45	"	2-12	0.3215	60	4.9	1.094	22		
46	"	2-12	0.1754	90	15.0	0.130	43		
47	"	2-12	0.0167	150	15.0	0.007	15		
48	"	2-12	0.1666	150	4.9	0.227	20	0.343	111.
49	10/20/77	2-13	0.2312	60	4.9	0.786	22		
50	"	2-13	0.1179	90	15.0	0.087	43		
51	"	2-13	0.0196	100	15.0	0.013	15		
52	"	2-13	0.0673	92	4.9	0.149	20	0.242	78.2
53	"	2-14	0.4635	60	4.9	1.577	22		
54	"	2-14	0.1127	90	15.0	0.083	43		
55	"	2-14	0.0025	90	15.0	0.002	15		
56	"	2-14	0.1566	90	4.9	0.335	20	0.450	145.
57	10/21/77	2-15	0.2007	60	4.9	0.683	22		
58	"	2-15	0.4978	62	15.0	0.535	43		
59	"	2-15	0.0071	120	15.0	0.004	15		
60	"	2-15	0.0755	120	4.9	0.128	20	0.407	131.
61	"	2-16	0.0963	60	4.9	0.328	22		
62	"	2-16	0.7421	60	15.0	0.825	43		
63	"	2-16	0.0112	120	15.0	0.006	15		
64	"	2-16	0.1309	120	4.9	0.223	20	0.472	153.

(continued)

* Percent of total flow going into the baghouse.

TABLE A-2. (continued)

Inlet Filter Number	Date Taken	Corresponding Outlet Sample	Inlet Material Weight (gm)	Sample Time (min)	Sample Flow Rate (ℓ/min)	Inlet Concentration (mg/ℓ)	Percent* Total Flow (%)	Weighted Average Concentration (mg/ℓ)	Total Plant Emission Rate (gm/min)
65	10/31/77	3-17	0.3414	60	4.9	1.161	22		
66	"	3-17	0.2213	60	15.0	0.246	43		
67	"	3-17	0	120	15.0	0	15		
68	"	3-17	0.0402	120	4.9	0.068	20	0.375	121.
69	"	3-18	0.6413	60	4.9	2.181	22		
70	"	3-18	0.1904	60	15.0	0.212	43		
71	"	3-18	0.0151	120	15.0	0.008	15		
72	"	3-18	0.0195	120	4.9	0.033	20	0.579	187.
73	11/01/77	3-19	0.3141	60	4.9	1.068	22		
74	"	3-19	0.2464	60	15.0	0.274	43		
75	"	3-19	0.1397	120	15.0	0.078	15		
76	"	3-19	0.5891	120	4.9	1.002	20	0.565	182.
77	"	3-20	0.3357	60	4.9	1.142	22		
78	"	3-20	0.2400	60	15.0	0.267	43		
79	"	3-20	0.0274	120	15.0	0.015	15		
80	"	3-20	0.0612	120	4.9	0.104	20	0.389	126.
81	11/02/77	3-21	0.4010	60	4.9	1.364	22		
82	"	3-21	0.2086	60	15.0	0.232	43		
83	"	3-21	0.0093	120	15.0	0.005	15		
84	"	3-21	0.0560	120	4.9	0.095	20	0.419	136.
85	"	3-22	0.1367	60	4.9	0.465	22		
86	"	3-22	0.7045	60	15.0	0.783	43		
87	"	3-22	0.0420	120	15.0	0.023	15		
88	"	3-22	0.1030	120	4.9	0.175	20	0.477	154.
89	11/03/77	3-23	0.2216	60	4.9	0.754	22		
90	"	3-23	0.0048	150	15.0	0.002	43		
91	"	3-23	0	121	15.0	0	15		
92	"	3-23	0.0784	121	4.9	0.132	20	0.193	62.4
93	"	3-24	0.0734	60	4.9	0.250	22		
94	"	3-24	0.0073	60	15.0	0.008	43		
95	"	3-24	0.0253	120	15.0	0.014	15		
96	"	3-24	0.2506	120	4.9	0.426	20	0.146	47.1

(continued)

* Percent of total flow going into the baghouse.

TABLE A-2. (continued)

Inlet Filter Number	Date Taken	Corresponding Outlet Sample	Inlet Material Weight (gm)	Sample Time (min)	Sample Flow Rate (ℓ/min)	Inlet Concentration (mg/ℓ)	Percent* Total Flow (%)	Weighted Average Concentration (mg/ℓ)	Total Plant Emission Rate (gm/min)
97	11/04/77	3-25	0.0970	60	4.9	0.330	22		
98	"	3-25	0.0027	60	15.0	0.003	43		
99	"	3-25	0.0045	120	15.0	0.003	15		
100	"	3-25	0.1186	120	4.9	0.202	20	0.115	37.1
101	"	3-26	0.2726	70	4.9	0.927	22		
102	"	3-26	0	70	15.0	0	43		
103	"	3-26	0.0029	120	15.0	0.002	15		
104	"	3-26	0.0988	120	4.9	0.168	20	0.238	76.8
105	11/14/77	4-27	0.0926	82	4.9	0.230	22		
106	"	4-27	0.0433	180	15.0	0.016	43		
107	"	4-27	0.0206	180	15.0	0.008	15		
108	"	4-27	0.3300	180	4.9	0.374	20		
109	"	4-27	0.2922	61	4.9	0.978	22		
110	"	4-27	0.0282	37	4.9	0.156	22	0.383	124.
111	"	4-28	0.3464	180	4.9	0.393	22		
112	"	4-28	0.0651	180	15.0	0.024	43		
113	"	4-28	0	180	15.0	0	15		
114	"	4-28	0.3280	180	4.9	0.372	20	0.171	55.3
115	11/15/77	4-29	0.7054	180	4.9	0.799	22		
116	"	4-29	0.1172	180	15.0	0.043	43		
117	"	4-29	0	180	15.0	0	15		
118	"	4-29	0.0855	100	4.9	0.097	20	0.214	69.0
119	"	4-30	0.2586	180	4.9	0.293	22		
120	"	4-30	0.1787	180	15.0	0.066	43		
121	"	4-30	0.0820	180	15.0	0.030	15		
122	"	4-30	0.1915	180	4.9	0.217	20	0.141	45.5
123	11/16/77	4-31	0.7277	180	4.9	0.825	22		
124	"	4-31	0.2048	180	15.0	0.076	43		
125	"	4-31	0.0016	180	15.0	0.001	15		
126	"	4-31	0.0750	180	4.9	0.085	20	0.231	74.7
127	"	4-32	0.2333	180	4.9	0.265	22		
128	"	4-32	0.5849	180	15.0	0.217	43		

(continued)

* Percent of total flow going into the baghouse.

TABLE A-2. (continued)

Inlet Filter Number	Date Taken	Corresponding Outlet Sample	Inlet Material Weight (gm)	Sample Time (min)	Sample Flow Rate (ℓ/min)	Inlet Concentration (mg/ℓ)	Percent* Total Flow (%)	Weighted Average Concentration (mg/ℓ)	Total Plant Emission Rate (gm/min)
129	11/16/77	4-32	0.0045	180	15.0	0.002	15		
130	"	4-32	0.3016	180	4.9	0.036	20	0.159	51.4
131	11/17/77	4-33	0.5487	180	4.9	0.622	22		
132	"	4-33	0.9732	180	15.0	0.360	43		
133	"	4-33	0.0244	180	15.0	0.009	15		
134	"	4-33	0.0576	180	4.9	0.065	20	0.314	101.
135	"	4-34	012431	180	4.9	0.276	22		
136	"	4-34	0.5477	180	15.0	0.203	43		
137	"	4-34	0.0055	180	15.0	0.002	15		
138	"	4-34	0.2753	180	4.9	0.312	20	0.211	68.1
139	11/18/77	4-35	0.3274	180	4.9	0.371	22		
140	"	4-35	0.2620	180	15.0	0.097	43		
141	"	4-35	0.0068	180	15.0	0.003	15		
142	"	4-35	0.0304	180	4.9	0.034	20	0.131	42.2
143	"	4-36	0.7211	180	4.9	0.818	22		
144	"	4-36	0.0130	180	15.0	0.005	43		
145	"	4-36	0.0706	180	15.0	0.026	15		
146	"	4-36	0.1990	180	4.9	0.226	20	0.231	74.7
147	11/30/77	5-37	0.6096	120	4.9	1.037	22		
148	"	5-37	0	120	15.0	0	43		
149	"	5-37	0.0008	120	15.0	0	15		
150	"	5-37	0.0489	120	4.9	0.083	20	0.245	79.0
151	"	5-38	0.2639	120	4.9	0.449	22		
152	"	5-38	0.0961	120	15.0	0.053	43		
153	"	5-38	0.5855	120	15.0	0.325	15		
154	"	5-38	0.0443	120	4.9	0.075	20	0.185	59.9
155	12/01/77	5-39	0.0136	120	4.9	0.023	22		
156	"	5-39	0.2343	120	15.0	0.130	43		
157	"	5-39	0.1071	120	15.0	0.060	15		
158	"	5-39	0	120	4.9	0	20	0.070	22.6
159	"	5-40	0.1202	120	4.9	0.204	22		
160	"	5-40	0.3951	120	15.0	0.220	43		

(continued)

* Percent of total flow going into the baghouse.

TABLE A-2. (continued)

Inlet Filter Number	Date Taken	Corresponding Outlet Sample	Inlet Material Weight (gm)	Sample Time (min)	Sample Flow Rate (ℓ/min)	Inlet Concentration (mg/ℓ)	Percent* Total Flow (%)	Weighted Average Concentration (mg/ℓ)	Total Plant Emission Rate (gm/min)
161	12/01/77	5-40	0.0112	120	15.0	0.006	15		
162	"	5-40	0.1002	120	4.9	0.170	20	0.174	56.3
163	12/02/77	5-41	0.3234	120	4.9	0.550	22		
164	"	5-41	0.1024	120	15.0	0.007	43		
165	"	5-41	0.0007	120	15.0	0	15		
166	"	5-41	0.1193	120	4.9	0.203	20	0.165	53.2
167	"	5-42	0.3310	120	4.9	0.563	22		
168	"	5-42	0.3169	120	15.0	0.176	43		
169	"	5-42	0.6435	120	15.0	0.360	15		
170	"	5-42	0.0044	120	4.9	0.007	20	0.261	84.1
171	12/05/77	5-43	0.5818	120	4.9	0.989	22		
172	"	5-43	0	120	15.0	0	43		
173	"	5-43	0.0143	120	15.0	0.008	15		
174	"	5-43	0.0896	120	4.9	0.152	20	0.249	80.5
175	"	5-44	0.4767	120	4.9	0.811	22		
176	"	5-44	0.2842	120	15.0	0.158	43		
177	"	5-44	0.0063	120	15.0	0.004	15		
178	"	5-44	0.0940	120	4.9	0.160	20	0.279	90.1
179	12/06/77	5-45	0.4045	120	4.9	0.688	22		
180	"	5-45	0.0006	120	15.0	0	43		
181	"	5-45	0.0240	120	15.0	0.013	15		
182	"	5-45	0.0525	120	4.9	0.089	20	0.171	55.3
183	"	5-46	0.2632	120	4.9	0.448	22		
184	"	5-46	0.0009	120	15.0	0.001	43		
185	"	5-46	0	120	15.0	0	15		
186	"	5-46	0.0084	120	4.9	0.014	20	0.102	32.9
187	01/16/78	7-47	0.6029	120	4.9	1.025	22		
188	"	7-47	0.0016	120	15.0	0.001	43		
189	"	7-47	0.0059	120	15.0	0.003	15		
190	"	7-47	0.0753	120	4.9	0.128	20	0.252	81.3
191	"	7-48	0.3766	120	4.9	0.640	22		
192	"	7-48	0.0134	120	15.0	0.007	43		

(continued)

* Percent of total flow going into the baghouse.

TABLE A-2. (continued)

Inlet Filter Number	Date Taken	Corresponding Outlet Sample	Inlet Material Weight (gm)	Sample Time (min)	Sample Flow Rate (ℓ/min)	Inlet Concentration (mg/ℓ)	Percent* Total Flow (%)	Weighted Average Concentration (mg/ℓ)	Total Plant Emission Rate (gm/min)
193	01/16/78	7-48	0.0389	120	15.0	0.022	15		
194	"	7-48	0.0069	120	4.9	0.012	20	0.150	48.3
195	01/17/78	7-49	0.3229	120	4.9	0.549	22		
196	"	7-49	0.0175	120	15.0	0.010	43		
197	"	7-49	0.0490	120	15.0	0.027	15		
198	"	7-49	0.0057	120	4.9	0.010	20	0.131	42.3
199	01/18/78	7-51	0.0759	101.6	4.9	0.153	22		
200	"	7-51	0.0088	101.6	15.0	0.006	43		
201	"	7-51	0.0299	101.6	15.0	0.020	15		
202	"	7-51	0.0100	101.6	4.9	0.020	20	0.043	14.0
203	01/19/78	7-52	0.1621	120	4.9	0.276	22		
204	"	7-52	0.0022	120	15.0	0.001	43		
205	"	7-52	0.0152	120	15.0	0.008	15		
206	"	7-52	0.0244	120	4.9	0.041	20	0.071	22.8
207	02/6/78	8-53	0.2570	120	4.9	0.437	22		
208	"	8-53	0.4247	120	15.0	0.236	43		
209	"	8-53	0.0112	120	15.0	0.506	15		
210	"	8-53	0.0267	120	4.9	0.045	20	0.208	67.0
211		Not Used							
212		" "							
213		" "							
214		" "							
215	02/8/78	8-54	0.7854	120	4.9	1.353	22		
216	"	8-54	0.1388	120	15.0	0.077	43		
217	"	8-54	0.3278	120	15.0	0.182	15		
218	"	8-54	0.0187	120	4.9	0.032	20	0.364	118.
219	"	8-55	0.1618	120	4.9	0.275	22		
220	"	8-55	0.0678	120	15.0	0.038	43		
221	"	8-55	0.1366	120	15.0	0.076	15		
222	"	8-55	0.0381	120	4.9	0.065	20	0.101	32.7
223	02/9/78	8-56	0.2754	120	4.9	0.468	22		
224	"	8-56	0.1174	120	15.0	0.065	43		

(continued)

* Percent of total flow going into the baghouse.

TABLE A-2. (continued)

Inlet Filter Number	Date Taken	Corresponding Outlet Sample	Inlet Material Weight (gm)	Sample Time (min)	Sample Flow Rate (ℓ/min)	Inlet Concentration (mg/ℓ)	Percent* Total Flow (%)	Weighted Average Concentration (mg/ℓ)	Total Plant Emission Rate (gm/min)
225	02/9/78	8-56	0.4372	120	15.0	0.243	15		
226	"	8-56	0.0165	120	4.9	0.028	20	0.173	55.8
227	"	8-57	0.2254	120	4.9	0.383	22		
228	"	8-57	0.3617	120	15.0	0.201	43		
229	"	8-57	0.0083	120	15.0	0.005	15		
230	"	8-57	0.0350	120	4.9	0.060	20	0.183	59.2
231	02/10/78	8-58	0.1315	120	4.9	0.224	22		
232	"	8-58	0.1523	120	15.0	0.085	43		
233	"	8-58	0.0549	120	15.0	0.031	15		
234	"	8-58	0.0019	120	4.9	0.003	20	0.091	29.4
235	02/20/78	11-59	0.1271	120	4.9	0.216	22		
236	"	11-59	0.0236	120	15.0	0.013	43		
237	"	11-59	0.0897	120	15.0	0.050	15		
238	"	11-59	0.2546	120	4.9	0.433	20	0.147	47.5
239	"	11-60	0.2038	120	4.9	0.347	22		
240	"	11-60	0.	120	15.0	0	43		
241	"	11-60	0.0179	120	15.0	0.007	15		
242	"	11-60	0.1834	120	4.9	0.312	20	0.140	45.1
243	02/21/78	11-61	0.2534	120	4.9	0.431	22		
244	"	11-61	0	120	15.0	0.	43		
245	"	11-61	0.0111	120	15.0	0.006	15		
246	"	11-61	0.0804	120	4.9	0.137	20	0.123	39.7
247	"	11-62	0.5207	120	4.9	0.886	22		
248	"	11-62	0.0004	120	15.0	0	43		
249	"	11-62	0.0134	120	15.0	0.007	15		
250	"	11-62	0.2266	120	4.9	0.385	20	0.273	88.1
251	02/22/78	11-63	0.2550	120	4.9	0.434	22		
252	"	11-63	0.0020	120	15.0	0.001	43		
253	"	11-63	0.0065	120	15.0	0.004	15		
254	"	11-63	0.0701	120	4.9	0.119	20	0.120	38.8
255	"	11-64	0.2925	120	4.9	0.497	22		
256	"	11-64	0.0032	120	15.0	0.002	43		
257	"	11-64	0.0036	120	15.0	0.002	15		

(continued)

* Percent of total flow going into the baghouse.

TABLE A-2. (continued)

Inlet Filter Number	Date Taken	Corresponding Outlet Sample	Inlet Material Weight (gm)	Sample Time (min)	Sample Flow Rate (ℓ/min)	Inlet Concentration (mg/ℓ)	Percent* Total Flow (%)	Weighted Average Concentration (mg/ℓ)	Total Plant Emission Rate (gm/min)
258	02/22/78	11-64	0.0801	120	4.9	0.136	20	0.138	44.4
259	02/23/78	11-65	0.1744	120	4.9	0.297	22		
260	"	11-65	0.0793	120	15.0	0.044	43		
261	"	11-65	0.0009	120	15.0	0.001	15		
262	"	11-65	0.0424	120	4.9	0.072	20	0.099	31.9
263	"	11-66	0.2920	120	4.9	0.497	22		
264	"	11-66	0.0966	120	15.0	0.054	43		
265	"	11-66	0.0296	120	15.0	0.016	15		
266	"	11-66	0.0112	120	4.9	0.019	20	0.139	44.8
267	02/24/78	11-67	0.3464	120	4.9	0.589	22		
268	"	11-67	0.1813	120	15.0	0.101	43		
269	"	11-67	0.0147	120	15.0	0.008	15		
270	"	11-67	0.0155	120	4.9	0.026	20	0.179	57.9
271	03/13/78	9-68	0.4719	120	4.9	0.803	22		
272	"	9-68	0.1190	120	15.0	0.066	43		
273	"	9-68	0.0962	120	15.0	0.053	15		
274	"	9-68	0.0588	120	4.9	0.100	20	0.232	75.2
275	"	9-69	0.3763	120	4.9	0.640	22		
276	"	9-69	0.1751	120	15.0	0.097	43		
277	"	9-69	0.0015	120	15.0	0.001	15		
278	"	9-69	0.0312	120	4.9	0.053	20	0.193	62.4
279	03/14/78	9-70	0.2316	120	4.9	0.394	22		
280	"	9-70	0.6045	120	15.0	0.336	43		
281	"	9-70	0.0493	120	15.0	0.027	15		
282	"	9-70	0.2121	120	4.9	0.361	20	0.307	99.2
283	"	9-71	0.3237	120	4.9	0.551	22		
284	"	9-71	0.8418	120	15.0	0.468	43		
285	"	9-71	0.0228	120	15.0	0.013	15		
286	"	9-71	0.1937	120	4.9	0.329	20	0.390	126.
287	03/15/78	9-72	0.2468	77	4.9	0.654	22		
288	"	9-72	0.6208	77	15.0	0.537	43		
289	"	9-72	0.0026	120	15.0	0.001	15		
290	"	9-72	0.4784	120	4.9	0.814	20	0.538	174.

(continued)

* Percent of total flow going into the baghouse.

TABLE A-2. (continued)

Inlet Filter Number	Date Taken	Corresponding Outlet Sample	Inlet Material Weight (gm)	Sample Time (min)	Sample Flow Rate (ℓ/min)	Inlet Concentration (mg/ℓ)	Percent* Total Flow (%)	Weighted Average Concentration (mg/ℓ)	Total Plant Emission Rate (gm/min)
291	03/15/78	9-73	0.1793	120	4.9	0.305	22		
292	"	9-73	0.7037	120	15.0	0.391	43		
293	"	9-73	0.0996	120	15.0	0.055	15	0.428	138.
294	"	9-73	0.5414	120	4.9	0.921	20		
295	03/16/78	9-74	0.6268	120	4.9	1.066	22		
296	"	9-74	0.6844	120	15.0	0.380	43		
297	"	9-74	0.2088	120	15.0	0.116	15	0.597	193.
298	"	9-74	0.5341	120	4.9	0.908	20		
299	"	9-75	0.4829	120	4.9	0.821	22		
300	"	9-75	0.4113	120	15.0	0.229	43		
301	"	9-75	0.0177	120	15.0	0.010	15	0.293	94.5
302	"	9-75	0.0357	120	4.9	0.061	20		
303	03/17/78	9-76	0.9491	105	4.9	1.845	22		
304	"	9-76	0.1647	105	15.0	0.105	43		
305	"	9-76	1.1789	120	15.0	0.655	15	0.571	184.
306	"	9-76	0.0646	120	4.9	0.110	20		
307	03/27/78	10-77	0.3362	120	4.9	0.572	22		
308	"	10-77	0.0536	120	15.0	0.030	43		
309	"	10-77	0.0178	120	15.0	0.010	15	0.233	75.2
310	"	10-77	0.2731	120	4.9	0.464	20		
311	"	10-78	0.1752	120	4.9	0.298	22		
312	"	10-78	0.0763	120	15.0	0.042	43		
313	"	10-78	0.0194	120	15.0	0.011	15	0.447	144.
314	"	10-78	1.0626	120	4.9	1.807	20		
315	03/28/78	10-79	0.3681	120	4.9	0.626	22		
316	"	10-79	0.0605	120	15.0	0.034	43		
317	"	10-79	0.0710	120	15.0	0.039	15	0.187	60.4
318	"	10-79	0.0854	120	4.9	0.145	20		
319	"	10-80	0.1651	120	4.9	0.281	22		
320	"	10-80	0.8060	120	15.0	0.448	43		
321	"	10-80	0.0075	120	15.0	0.004	15	0.358	116.
322	"	10-80	0.3033	120	4.9	0.516	20		

(continued)

* Percent of total flow going into the baghouse.

TABLE A-2. (continued)

Inlet Filter Number	Date Taken	Corresponding Outlet Sample	Inlet Material Weight (gm)	Sample Time (min)	Sample Flow Rate (ℓ/min)	Inlet Concentration (mg/ℓ)	Percent* Total Flow (%)	Weighted Average Concentration (mg/ℓ)	Total Plant Emission Rate (gm/min)
323	03/29/78	10-81	0.5036	120	4.9	0.856	22		
324	"	10-81	0.4197	120	15.0	0.233	43		
325	"	10-81	0.0096	120	15.0	0.005	15		
326	"	10-81	0.1909	120	4.9	0.325	20	0.354	114.
327	"	10-82	0.2124	120	4.9	0.361	22		
328	"	10-82	0.0049	120	15.0	0.003	43		
329	"	10-82	0.0720	120	15.0	0.040	15		
330	"	10-82	0.4133	120	4.9	0.703	20	0.227	73.4
331	03/30/78	10-83	0.5745	120	4.9	0.977	22		
332	"	10-83	0.4433	120	15.0	0.246	43		
333	"	10-83	0.4357	120	15.0	0.242	15		
334	"	10-83	0.0730	120	4.9	0.124	20	0.382	123.
335	"	10-84	0.7359	120	4.9	1.252	22		
336	"	10-84	0.3791	120	15.0	0.211	43		
337	"	10-84	0.9286	120	15.0	0.516	15		
338	"	10-84	0.0662	120	4.9	0.113	20	0.466	150.
339	03/31/78	10-85	0.2013	120	4.9	0.342	22		
340	"	10-85	0.2908	120	15.0	0.162	43		
341	"	10-85	0.0236	120	15.0	0.013	15		
342	"	10-85	0.0331	120	4.9	0.056	20	0.158	51.0
343	04/10/78	6-86	0.3059	120	4.9	0.520	22		
344	"	6-86	0.0575	120	15.0	0.032	43		
345	"	6-86	0.2063	120	15.0	0.115	15		
346	"	6-86	0.0153	120	4.9	0.026	20	0.151	48.7
347	"	6-87	0.2745	120	4.9	0.467	22		
348	"	6-87	0.2112	120	15.0	0.117	43		
349	"	6-87	0.1075	120	15.0	0.060	15		
350	"	6-87	0.1040	120	4.9	0.177	20	0.197	63.6
351	04/11/78	6-88	0.2770	120	4.9	0.471	22		
352	"	6-88	0.0923	120	15.0	0.051	43		
353	"	6-88	0.1633	120	15.0	0.091	15		
354	"	6-88	0.1377	120	4.9	0.234	20	0.186	60.0
355	"	6-89	0.4719	120	4.9	0.803	22		

(continued)

* Percent of total flow going into the baghouse.

TABLE A-2. (continued)

Inlet Filter Number	Date Taken	Corresponding Outlet Sample	Inlet Material Weight (gm)	Sample Time (min)	Sample Flow Rate (ℓ/min)	Inlet Concentration (mg/ℓ)	Percent* Total Flow (%)	Weighted Average Concentration (mg/ℓ)	Total Plant Emission Rate (gm/min)
356	04/11/78	6-89	0.0225	120	15.0	0.013	43		
357	"	6-89	1.0206	120	15.0	0.567	15		
358	"	6-89	0.1703	120	4.9	0.290	20	0.325	105.
359	04/12/78	6-90	0.3153	120	4.9	0.536	22		
360	"	6-90	0.6687	120	15.0	0.372	43		
361	"	6-90	0.0794	120	15.0	0.044	15		
362	"	6-90	0.1563	120	4.9	0.266	20	0.338	109.
363	"	6-91	0.1882	120	4.9	0.320	22		
364	"	6-91	0.0312	120	15.0	0.017	43		
365	"	6-91	2.5875	115	15.0	1.500	15		
366	"	6-91	0.0148	120	4.9	0.025	20	0.308	99.3
367	04/13/78	6-92	0.3380	120	4.9	0.575	22		
368	"	6-92	0.3169	120	15.0	0.176	43		
369	"	6-92	0.0299	120	15.0	0.017	15		
370	"	6-92	0.0332	120	4.9	0.056	20	0.216	69.7
371	"	6-93	0.1219	120	4.9	0.207	22		
372	"	6-93	0.1065	120	15.0	0.059	43		
373	"	6-93	0.7521	120	15.0	0.417	15		
374	"	6-93	0.0096	120	4.9	0.016	20	0.137	44.1

* Percent of total flow going into the baghouse.

TABLE A-3. OUTLET FIBER CONCENTRATION

Test No.- Sample No.	Total No. Grids	Total No. Fibers	Fibers / Grid	Std. Volume Air Sampled (SCM)	No. of Fibers / cm^2 of Filter x 10^6	No. of Fibers / SCM of Air x 10^7
1-1	1	161	161.	9.04	2.516	3.527
1-2	1	214	214.	11.46	3.344	3.697
1-3	2	178	89.0	11.64	1.391	1.514
1-4	1	275	275.	11.48	4.297	4.742
1-5	1	93	93.0	11.80	1.453	1.560
1-6	1	184	184.	11.66	2.875	3.124
1-7	1	231	231.	7.91	3.609	5.781
1-8	1	118	118.	5.85	1.844	3.995
2-9	2	151	75.5	11.88	1.180	1.258
2-10	2	210	105.	12.21	1.641	1.702
2-11	1	115	115.	12.19	1.797	1.868
2-12	1	164	164.	12.24	2.563	2.653
2-13	1	142	142.	12.14	2.219	2.316
2-14	1	120	120.	11.94	1.875	1.990
2-15	2	104	52.0	12.14	0.813	0.848
2-16	1	133	133.	12.35	2.078	2.132
3-17	2	157	78.5	12.42	1.227	1.251
3-18	1	169	169.	12.27	2.641	2.727
3-19	1	146	146.	12.40	2.281	2.331
3-20	1	135	135.	12.32	2.109	2.169
3-21	1	253	253.	12.94	3.953	3.871
3-22	2	180	90.0	12.25	1.406	1.454
3-23	2	162	81.0	12.63	1.266	1.270
3-24	1	100	100.	12.48	1.563	1.586
3-25	1	172	172.	12.75	2.688	2.671
3-26	2	170	85.0	12.04	1.328	1.398
4-27	1	109	109.	13.38	1.703	1.613
4-28	2	100	50.0	13.21	0.781	0.749
4-29	3	113	37.7	12.82	0.589	0.582
4-30	2	126	63.0	12.73	0.984	0.980
4-31	2	142	71.0	12.67	1.109	1.109
4-32	2	121	60.5	12.73	0.945	0.941
4-33	1	100	100.	12.65	1.563	1.565
4-34	2	118	59.0	12.68	0.922	0.921
4-35	2	100	50.0	12.77	0.781	0.775
4-36	2	122	61.0	12.60	0.953	0.958
5-37	2	107	53.5	8.11	0.836	1.306
5-38	1	104	104.	8.05	1.625	2.557
5-39	2	103	51.5	7.99	0.805	1.277
5-40	1	105	105.	7.92	1.641	2.625
5-41	1	268	268.	7.75	4.188	6.848
5-42	1	119	119.	7.75	1.859	3.038
5-43	2	114	57.0	7.92.	0.891	1.424
5-44	2	117	58.5	7.91	0.914	1.464
5-45	1	100	100.	7.66	1.563	2.585
5-46	1	210	210.	7.70	3.281	5.397

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TABLE A-3. (continued)

Test No.- Sample No.	Total No. Grids	Total No. Fibers	Fibers / Grid	Std. Volume Air Sampled (SCM)	No. of Fibers / cm^2 of Filter x 10^6	No. of Fibers / SCM of Air x 10^7
7-47	1	119	119.	8.23	1.859	2.862
7-48	3	105	35.0	8.35	0.547	0.830
7-49	6	100	16.7	7.47	0.261	0.442
7-51	4	100	25.0	6.61	0.391	0.749
7-52	2	108	54.0	8.05	0.844	1.328
8-53	1	120	120.	7.24	1.875	3.282
8-54	2	144	72.0	7.60	1.125	1.876
8-55	3	136	45.3	7.67	0.708	1.169
8-56	1	133	133.	7.54	2.078	3.492
8-57	2	212	106.	7.74	1.656	2.711
8-58	6	124	20.7	6.96	0.323	0.589
11-59	1	140	140.	7.61	2.188	3.640
11-60	3	157	52.3	7.78	0.817	1.330
11-61	3	162	54.0	7.61	0.844	1.406
11-62	2	153	76.5	7.76	1.195	1.952
11-63	4	127	31.8	7.29	0.497	0.864
11-64	5	118	23.6	7.56	0.369	0.618
11-65	7	110	15.7	7.26	0.245	0.427
11-66	4	108	27.0	7.47	0.422	0.716
11-67	3	107	35.7	7.33	0.558	0.964
9-68	2	195	97.5	8.28	1.523	2.330
9-69	2	176	88.0	8.28	1.375	2.104
9-70	2	165	82.5	7.97	1.289	2.048
9-71	1	204	204.	8.11	3.188	4.978
9-72	1	145	145.	8.17	2.266	3.512
9-73	1	179	179.	8.11	2.797	4.368
9-74	1	143	143.	7.88	2.234	3.592
9-75	2	170	85.0	7.89	1.328	2.132
9-76	1	255	255.	7.78	3.984	6.491
10-77	1	104	104.	8.38	1.625	2.456
10-78	1	131	131.	8.53	2.047	3.040
10-79	1	137	137.	8.34	2.141	3.252
10-80	1	150	150.	8.27	2.344	3.590
10-81	1	122	122.	8.32	1.906	2.902
10-82	2	191	95.5	8.26	1.492	2.289
10-83	2	133	66.5	8.41	1.039	1.565
10-84	1	153	153.	8.32	2.391	3.642
10-85	1	133	133.	8.16	2.078	3.226
6-86	2	120	60.0	8.55	0.938	1.389
6-87	1	192	192.	8.34	3.000	4.555
6-88	1	145	145.	8.12	2.266	3.536
6-89	1	140	140.	8.20	2.188	3.382
6-90	1	144	144.	8.08	2.250	3.529
6-91	1	112	112.	8.02	1.750	2.765
6-92	2	174	87.0	8.03	1.359	2.144
6-93	3	131	43.7	8.11	0.683	1.066

(continued)

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BOTTOM OF IMAGE AREA OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"

EPA-287 (Cln.) (4-76)

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TOP OF IMAGE AREA
DROPPED HEAD: BEGIN SECTIONS HERE

TABLE A-3. (continued)

Test No. - Sample No.	Total No. Grids	Total No. Fibers	Fibers / Grid	Std. Volume Air Sampled (SCM)	No. of Fibers / cm^2 of Filter x 10^5	No. of Fibers / SCM of Air x 10^6
12-1	4	114	28.5	8.24	3.945	6.066
12-2	3	114	38.0	7.74	5.260	8.610
12-3	4	123	30.8	8.66	4.256	6.227
12-4	2	104	52.0	8.81	7.197	10.350
12-5	10	53	5.3	8.52	0.734	1.091
12-6	10	41	4.1	8.45	0.568	0.851
12-7	4	116	29.0	8.59	4.013	5.919
12-8	2	152	76.0	8.43	10.519	15.810
12-9	5	128	25.6	8.40	3.543	5.344
12-10	2	118	59.0	8.27	8.166	12.511
13-1	10	99	9.9	8.35	1.370	2.079
13-2	5	107	21.4	8.50	2.962	4.415
13-3	6	111	18.5	8.52	2.561	3.808
13-4	8	104	13.0	8.58	1.799	2.657
13-5	5	115	23.0	8.30	3.183	4.859
13-6	3	105	35.0	8.23	4.844	7.457
13-7	3	118	39.3	8.19	5.444	8.423
13-8	7	108	15.4	8.14	2.135	3.323
13-9	4	113	28.3	8.19	3.910	6.049
13-10	1	102	102.0	8.20	14.118	21.814
14-1	8	104	13.0	8.60	1.799	2.650
14-2	2	119	59.5	8.47	8.235	12.318
14-3	3	109	36.3	8.47	5.029	7.523
14-4	3	114	38.0	8.50	5.260	7.841
14-5	3	143	47.6	8.42	6.597	9.927
14-6	4	140	35.0	8.45	4.844	7.263
14-7	4	133	33.3	8.57	4.602	6.804
14-8	5	111	22.2	8.48	3.073	4.591
14-9	5	109	21.8	8.46	3.017	4.518
14-10	4	116	29.0	8.47	4.014	6.004

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3/8"
BOTTOM OF IMAGE AREA OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS

EPA-287 (Cin.)
(4-76)

TABLE A-4. CUMULATIVE FREQUENCE DISTRIBUTION - PHASE I

Test No.- Sample No.	Fiber Length in Microns (% Less Than or Equal To)													
	0.39	0.55	0.78	1.17	1.56	1.95	2.34	3.13	4.30	5.85	7.81	11.72	15.62	>15.62
1-1	0.00	1.86	11.8	33.4	48.4	57.1	72.0	80.7	90.1	93.8	98.9	98.9	100.	
1-2	0.00	4.21	22.4	40.7	58.9	65.9	72.9	82.7	91.6	94.9	98.1	99.1	100.	
1-3	6.18	10.1	30.3	51.7	62.4	74.7	81.5	88.8	95.5	98.3	98.9	99.4	99.4	100.
1-4	1.82	6.91	25.5	46.5	58.5	70.2	77.8	84.7	89.5	93.5	95.3	98.5	99.3	100.
1-5	0.00	0.00	17.2	29.0	45.2	54.8	64.5	76.3	88.2	92.5	95.7	100.		
1-6	1.63	7.07	22.8	42.9	58.7	66.8	73.4	85.7	90.2	94.0	97.3	98.4	98.9	100.
1-7	0.43	6.49	29.4	49.8	60.6	69.3	74.9	83.5	87.4	93.9	96.5	99.6	99.6	100.
1-8	4.24	13.6	30.5	46.6	51.7	61.9	70.3	83.1	87.3	94.1	96.6	97.5	98.3	100.
2-9	0.66	1.99	13.2	29.1	39.1	49.7	58.3	74.8	83.4	90.7	94.0	98.7	99.3	100.
2-10	0.48	0.95	6.67	22.9	35.2	46.7	58.1	72.6	84.8	94.3	96.2	99.0	99.5	100.
2-11	0.87	0.87	15.7	41.7	52.2	59.1	65.2	74.8	83.5	88.7	95.7	99.1	100.	
2-12	1.83	3.05	12.2	19.5	31.1	39.6	45.1	66.5	81.1	89.6	96.3	100.		
2-13	0.00	0.70	14.8	22.5	37.3	53.5	59.9	73.2	80.3	88.0	93.0	98.6	99.3	100.
2-14	0.83	1.67	11.7	23.3	36.7	48.3	58.3	70.0	83.3	90.0	95.0	99.2	100.	
2-15	0.96	1.92	15.4	27.9	43.3	52.9	58.7	75.0	83.7	87.5	90.4	96.2	97.1	100.
2-16	2.26	2.26	5.26	17.3	29.3	41.4	53.4	62.4	73.7	86.5	94.0	98.5	100.	
3-17	1.91	3.82	24.2	40.8	50.3	58.6	63.7	72.6	81.5	89.2	91.7	98.1	98.7	100.
3-18	2.37	5.33	23.1	40.8	57.4	65.1	68.0	76.3	85.8	92.3	96.4	98.2	98.8	100.
3-19	2.74	4.11	23.3	37.7	55.5	65.1	69.2	76.7	84.9	93.2	98.6	99.3	99.3	100.
3-20	0.00	0.00	13.3	31.9	48.1	58.5	63.7	79.3	88.9	96.3	97.0	97.0	98.5	100.
3-21	9.09	15.4	26.5	45.5	57.3	65.6	71.9	81.0	85.4	93.3	97.2	98.8	99.6	100.
3-22	1.67	5.56	26.7	41.7	52.2	60.6	71.1	84.4	91.1	95.0	97.2	98.3	99.4	100.
3-23	0.00	2.47	19.1	35.8	55.6	69.1	76.5	89.5	95.1	97.5	98.1	99.4	100.	
3-24	15.0	18.0	36.0	59.0	74.0	85.0	92.0	96.0	97.0	99.0	99.0	100.		
3-25	6.98	7.56	22.1	46.5	55.8	61.6	68.0	77.3	86.0	91.3	97.7	99.4	99.4	100.
3-26	0.00	1.18	19.4	44.7	65.9	74.1	81.8	89.4	92.4	97.1	99.4	100.		
4-27	11.0	15.6	37.6	50.5	66.1	69.7	78.0	89.9	93.6	94.5	98.2	100.		
4-28	5.00	7.00	24.0	39.0	58.0	65.0	75.0	81.0	89.0	97.0	98.0	100.		
4-29	5.31	7.96	23.0	40.7	63.7	68.1	78.8	90.3	97.3	98.2	99.1	99.1	99.1	100.
4-30	9.52	12.7	23.8	37.3	50.0	59.5	73.8	84.1	92.9	97.6	99.2	99.2	99.2	100.
4-31	1.41	2.82	10.6	26.1	40.1	55.6	64.1	73.9	85.2	90.8	96.5	99.3	100.	
4-32	1.65	3.31	16.5	31.4	51.2	58.7	68.6	78.5	83.5	91.7	96.7	100.		
4-33	10.0	10.0	28.0	39.0	48.0	58.0	64.0	75.0	81.0	88.0	95.0	96.0	97.0	100.
4-34	12.7	15.3	35.6	49.2	62.7	67.8	73.7	83.1	89.0	96.6	98.3	99.2	100.	
4-35	6.00	8.00	23.0	37.0	46.0	56.0	68.0	81.0	92.0	96.0	99.0	100.		
4-36	13.0	21.3	37.7	53.3	68.0	69.7	75.4	80.3	89.3	94.3	97.5	100.		

(continued)

TABLE A-4. (continued)

Test No.- Sample No.	Fiber Length in Microns (% Less Than or Equal To)													
	0.39	0.55	0.78	1.17	1.56	1.95	2.34	3.13	4.30	5.85	7.81	11.72	15.62	>15.62
5-37	12.1	15.0	29.0	47.7	65.4	70.1	77.6	84.1	89.7	95.3	99.1	100.		
5-38	7.69	13.5	30.8	49.0	68.3	80.8	90.4	97.1	99.0	100.				
5-39	9.71	12.6	34.0	53.4	70.9	75.7	82.5	91.3	93.2	98.1	99.0	100.		
5-40	7.62	7.62	21.9	41.0	58.1	69.5	76.2	88.6	96.2	99.0	99.0	100.		
5-41	14.2	17.5	39.9	54.1	62.7	71.3	76.9	85.4	94.0	97.4	98.5	100.		
5-42	9.24	13.4	26.1	41.2	58.8	65.5	73.1	81.5	84.0	94.1	95.0	100.		
5-43	10.5	12.3	19.3	38.6	53.5	63.2	71.1	82.5	89.5	96.5	98.2	99.1	99.1	100.
5-44	12.8	14.5	25.6	42.7	55.6	62.4	70.1	78.6	84.6	92.3	94.9	98.3	98.3	100.
5-45	14.0	17.0	30.0	49.0	64.0	68.0	76.0	87.0	88.0	95.0	98.0	99.0	100.	
5-46	10.0	13.3	29.5	46.7	63.3	69.5	78.1	89.5	93.8	97.1	98.6	99.0	100.	
7-47	10.9	13.4	26.1	37.8	47.1	56.3	66.4	76.5	82.4	92.4	98.3	100.		
7-48	19.0	26.7	47.6	66.7	74.3	79.0	85.7	90.5	94.3	97.1	97.1	99.0	100.	
7-49	12.0	16.0	30.0	53.0	67.0	73.0	81.0	91.0	94.0	97.0	99.0	100.		
7-51	8.00	12.0	25.0	38.0	59.0	69.0	77.0	83.0	96.0	98.0	98.0	99.0	99.0	100.
7-52	14.8	16.7	30.6	51.9	65.0	69.4	78.7	88.9	94.4	97.2	97.2	98.1	100.	
8-53	9.17	17.5	30.0	55.0	69.2	79.2	85.0	91.7	94.2	98.3	99.2	100.		
8-54	13.2	16.7	38.2	56.3	70.1	79.9	83.3	91.7	96.5	98.6	99.3	100.		
8-55	8.82	16.9	40.4	63.2	74.3	80.9	84.6	89.7	92.6	97.1	97.1	100.		
8-56	4.51	15.8	35.3	52.6	70.7	77.4	84.2	89.5	94.7	98.5	99.2	99.2	100.	
8-57	2.83	8.96	26.9	40.1	53.8	65.1	70.8	80.7	89.6	93.9	99.1	100.		
8-58	4.84	12.9	33.9	58.9	67.7	75.8	83.9	91.1	94.4	99.2	100.			
11-59	6.43	14.3	30.0	52.1	63.6	75.0	82.1	86.4	89.3	95.0	98.6	100.		
11-60	5.10	14.0	33.1	57.3	72.6	78.3	81.5	87.3	91.1	95.5	96.8	100.		
11-61	1.85	3.07	21.0	41.4	53.1	67.9	76.5	83.3	91.4	96.9	98.8	99.4	99.4	100.
11-62	3.92	12.4	35.3	52.3	64.1	77.1	84.3	88.9	92.2	94.1	96.7	99.3	100.	
11-63	4.72	11.8	24.4	46.5	57.5	69.3	76.4	83.5	90.6	93.7	96.9	98.4	100.	
11-64	2.54	5.93	23.7	50.8	71.2	80.5	85.6	94.1	98.3	99.2	99.2	100.		
11-65	0.00	3.64	11.8	33.6	49.1	60.9	70.0	79.1	84.5	90.9	94.5	98.2	98.2	100.
11-66	5.56	12.0	25.9	52.8	75.0	86.1	88.9	94.4	95.4	98.1	100.			
11-67	1.87	5.61	23.4	47.7	55.1	65.4	74.8	79.4	93.5	98.1	99.1	99.1	99.1	100.
9-68	4.62	6.67	20.0	41.0	51.8	68.2	77.4	85.6	91.3	93.3	94.9	98.5	99.5	100.
9-69	9.09	14.2	34.1	53.4	64.2	75.0	81.3	89.2	96.0	97.7	98.9	99.4	99.4	100.
9-70	5.45	7.88	17.6	37.6	46.7	57.6	66.1	77.6	86.1	91.5	97.0	99.4	99.4	100.
9-71	7.35	11.3	23.5	43.1	53.9	64.7	75.0	82.4	90.7	94.6	96.6	97.5	99.0	100.
9-72	3.45	11.7	20.7	36.6	46.9	55.9	64.1	77.9	88.3	91.7	96.6	99.3	99.3	100.
9-73	5.59	15.6	27.4	49.7	65.4	75.4	78.2	85.5	92.7	96.1	98.3	99.4	99.4	100.

(continued)

TABLE A-4 (continued)

Test No.- Sample No.	Fiber Length in Microns (% Less Than or Equal To)													
	0.39	0.55	0.78	1.17	1.56	1.95	2.34	3.13	4.30	5.85	7.81	11.72	15.62	>15.62
9-74	8.39	11.9	30.8	49.7	57.3	72.0	79.0	87.4	90.9	95.1	98.6	100.		
9-75	6.47	10.0	23.5	38.8	55.3	66.5	77.1	83.5	92.9	96.5	98.8	99.4	99.4	100.
9-76	8.63	17.3	37.6	62.4	71.8	80.0	83.5	88.6	94.5	96.1	98.4	99.6	100.	
10-77	17.3	33.7	53.8	68.3	76.9	84.6	85.6	92.3	96.2	100.				
10-78	15.3	26.0	43.5	61.1	71.0	78.6	84.0	89.3	90.8	93.9	96.2	97.7	98.5	100.
10-79	2.92	9.49	24.8	48.2	61.3	71.5	79.6	88.3	93.4	94.2	97.1	99.3	100.	
10-80	8.00	18.0	40.0	60.0	75.3	79.3	84.7	87.3	90.0	94.7	97.3	99.3	100.	
10-81	4.92	5.74	18.9	37.7	52.5	58.2	65.6	76.2	82.8	91.0	97.5	98.4	99.2	100.
10-82	13.1	23.6	44.0	65.4	76.4	83.2	87.4	92.1	94.2	97.4	99.5	100.		
10-83	9.77	17.3	31.6	49.6	66.2	75.9	81.2	91.7	94.7	99.2	100.			
10-84	13.1	19.0	45.1	60.1	70.6	80.4	84.3	92.8	96.7	99.3	100.			
10-85	6.02	15.0	30.8	45.9	55.6	67.7	75.9	85.0	92.5	96.2	99.2	99.2	100.	
6-86	17.5	28.3	50.8	61.7	70.0	78.3	82.5	90.8	92.5	95.8	98.3	99.2	99.2	100.
6-87	3.13	9.90	31.8	55.7	69.8	77.1	82.8	86.5	91.1	95.8	99.5	100.		
6-88	13.8	20.0	46.9	64.8	74.5	84.1	89.7	92.4	97.2	98.6	100.			
6-89	7.86	8.57	16.4	35.0	51.4	60.0	70.0	77.9	87.1	92.9	95.7	97.9	99.3	100.
6-90	9.03	14.6	29.9	45.1	64.6	72.9	79.9	92.4	95.1	97.2	98.6	99.3	100.	
6-91	9.82	11.6	25.0	33.9	53.6	60.7	67.9	83.9	88.4	95.5	98.2	100.		
6-92	3.45	4.02	12.6	27.6	42.5	56.3	64.9	80.5	90.2	94.3	98.3	99.4	100.	
6-93	9.92	13.0	22.1	38.2	51.9	58.0	73.3	80.2	89.3	96.9	98.5	100.		

TABLE A-5. CUMULATIVE FREQUENCY DISTRIBUTION OF LENGTHS - SERIES II

Test No.- Sample No.	Fiber Length in Microns (% Less Than)											
	1.5	3.0	4.5	6.0	7.5	9.0	10.5	12.0	13.5	15.0	16.5	18.0
12-1	56.1	78.9	87.7	92.1	93.0	93.9	94.8	98.3	98.3	98.3	100	100
12-2	55.3	84.2	94.7	97.3	98.2	98.2	99.1	99.1	99.1	100	100	100
12-3	71.5	88.6	95.9	99.2	100	100	100	100	100	100	100	100
12-4	73.1	90.4	97.1	97.1	99.0	100	100	100	100	100	100	100
12-5	75.5	96.2	96.2	98.1	98.1	100	100	100	100	100	100	100
12-6	70.7	87.8	95.1	100	100	100	100	100	100	100	100	100
12-7	49.1	77.5	91.3	97.3	99.0	100	100	100	100	100	100	100
12-8	63.2	89.5	96.7	98.7	98.7	99.4	99.4	100	100	100	100	100
12-9	63.3	93.0	98.5	100	100	100	100	100	100	100	100	100
12-10	53.8	80.3	90.6	97.4	98.3	99.2	99.2	100	100	100	100	100
13-1	53.5	80.0	85.8	93.9	98.9	100	100	100	100	100	100	100
13-2	70.1	89.7	97.2	100	100	100	100	100	100	100	100	100
13-3	47.7	78.3	91.8	97.2	99.0	99.0	99.0	99.0	99.0	99.0	99.0	100
13-4	58.6	85.5	94.2	98.0	100	100	100	100	100	100	100	100
13-5	67.0	88.7	93.0	97.3	97.3	97.3	98.2	99.1	99.1	99.1	100	100
13-6	63.8	90.5	96.2	99.1	100	100	100	100	100	100	100	100
13-7	41.5	74.6	87.3	95.8	98.3	98.3	99.1	100	100	100	100	100
13-8	58.3	80.5	91.6	96.2	99.1	99.0	99.0	99.0	100	100	100	100
13-9	50.4	81.4	92.0	95.5	97.3	98.2	99.1	100	100	100	100	100
13-10	56.9	82.4	87.3	92.2	94.2	97.1	97.1	98.1	98.1	98.1	98.1	100
14-1	54.8	88.4	95.1	99.0	99.0	99.0	100	100	100	100	100	100
14-2	54.6	84.8	89.0	92.4	95.8	98.3	98.3	98.3	98.3	98.3	98.3	100
14-3	59.6	81.6	88.0	95.3	96.2	96.2	98.0	98.0	98.9	98.9	100	100
14-4	54.4	82.5	93.0	97.4	98.3	100	100	100	100	100	100	100
14-5	58.7	87.4	94.4	97.2	98.6	98.6	98.6	98.6	98.6	98.6	98.6	100
14-6	63.6	83.6	91.5	95.1	97.2	97.2	98.6	98.6	100	100	100	100
14-7	42.1	72.2	85.0	91.0	94.8	95.6	95.6	98.6	98.6	98.6	98.6	100
14-8	48.6	76.5	88.2	95.4	99.0	99.0	99.0	99.0	99.0	99.0	100	100
14-9	39.4	71.5	88.0	95.3	96.2	98.0	98.9	98.9	98.9	98.9	98.9	100
14-10	42.2	79.3	90.5	98.3	99.2	99.2	100	100	100	100	100	100

APPENDIX B

ANALYTICAL TECHNIQUES CONSIDERED FOR THE STUDY

Prior to initiation of Phase I of the baghouse sampling study, two analytical technicques were evaluated to determine their suitability for use on this study. They were:

- Atomic Absorption Analysis of Filter Samples (AA)
- Optical Microscopy Analysis of Filter Samples (OM)

The rationale for attempting to use one or both of these techniques was to attempt to acquire data at lower cost with shorter turn-around time.

The efforts and conclusions are described below.

ATOMIC ABSORPTION ANALYSIS

The sampling of the filters was done by cutting wedge-shaped sections from filters. The wedge-shaped sections from the several selected filters were analyzed for magnesium and calcium. Magnesium was used to monitor the asbestos in the baghouse effluent since magnesium is present in the non-asbestos part of the waste in small quantities. Magnesium is one-fourth by weight of chrysotile, which constitutes the major type of asbestos used. Calcium is used to monitor the concentration of the non-asbestos particulate effluents because little calcium is present in chrysotile asbestos while it is a major constituent of the cement used to bind the materials.

The method used for sample preparation is an adaption of a procedure in the EPA Method Handbook. Initially, the filter wedge is dissolved in a small amount of chloroform in a crucible, then heated in a muffle furnace at 525^{o}C for two hours. After cooling, the crucible is rinsed with two 2 ml portions of hot, 10% nitric acid. A swirling motion suspends the deposit which is then transferred to a 50 ml Griffin beaker. The acid solution is evaporated to dryness with gentle heating on a hot plate.

The following acid solutions further digest the sample,

- 2 ml concentrated nitric acid
- 2 ml concentrated nitric acid
- 2 ml concentrated hydrochloric acid

and are evaporated to dryness after each addition. 10 ml of 10% hydrochloric acid brings the final residue back into solution. A small amount of 2%

lanthanum chloride was added to the hydrochloric acid solution to chelate any phosphates.

Solutions of bulk waste samples are prepared using a similar procedure. Gentle heating with the following additions of concentrated acid solutions digest ten milligram samples of the bulk wastes:

- 5 ml concentrated nitric acid
- 5 ml concentrated hydrochloric acid
- 5 ml concentrated hydrochloric acid

The sample is evaporated to dryness after each addition.

The final residue is processed by the same procedure used for the filter samples. 10% hydrochloric acid with two drops of 2% lanthanum chloride solution brings back the residue into final solution. Filtering the final solution through a Nuclepore^{R} filter removes any undissolved silicate residue.

The solutions are brought to volume after the filtration, and the calcium and magnesium concentrations are determined using atomic absorption. The results of the samples run are presented in Tables B-1 and B-2.

TABLE B-1. ATOMIC ABSORPTION ANALYSIS ON EMISSION SAMPLES

Sample I.D.	Sample Time (min)	Mg Conc. on Filter (g/cm)	Ca Conc. on Filter (g/cm)	Ca/Mg Ratio
2-2	2	0.0138	0.022	1.6
2-8	8	0.078	0.136	1.75
3-10	10	0.110	0.17	1.55
1-30	30	0.603	1.00	1.66

OPTICAL MICROSCOPY ANALYSIS

The chief problem in attempting to obtain analysis of asbestos on Nuclepore membranes is the face that Nuclepore filters are birefringent with refractive indices (RI) of 1.584 and 1.616. Several immersion oils with RI's between 1.584 and 1.616 were tried, but all failed to reduce the interference caused by the birefringence of the filter which leaves the structure partially visible. The visible structure interferes with analysis.

Nuclepore corporation technical staff suggested using an oil with a RI in the same range plus using polarized transmitted light. This method works very well when using an oil with a RI of 1.616 to look at a filter with a pore size of 0.2 μm or less, however the pore structure of a 0.6 μm filter remains

TABLE B-2. ATOMIC ABSORPTION ANALYSIS ON BULK WASTE SAMPLES

Sample I.D.	Sample Wt (mg)	Magnesium (µg)	Calcium (µg)	Calcium/ Magnesium Ratio	Asbestos/Total Particulate Ratio*
Bulk 1	10.4	592	1040	1.76	0.228
Bulk 2	10.4	551	940	1.71	0.212
Bulk 3	10.6	604	1060	1.75	0.228
					Average: 0.223

* Asbestos/Total Particulate = [Mg Conc./Sample Wt][Asbestos/Mg Ratio]**

** Asbestos/Mg Ratio ≃ 4. Based on stochiometry of chrysotile asbestos.

visible under these conditions. Consequently, the attempts to use an immersion oil were stopped.

Another technique, that of dissolving the Nuclepore filter in *situ*, was also evaluated. The best solvent for Nuclepore membranes is chloroform. Five methods of filter dissolution were attempted.

The airborne asbestos data was compared to particle count data obtained from a Royco Particle Counter. This comparison is shown in Table B-3. The correlation coefficient between the data is -0.81, which implies that about 66% of the variation in the ratio is accounted for by the data. This degree of correlation was determined to be inadequate to allow IITRI to characterize the duct inlets using this technique.

A few drops of chloroform completely dissolve a Nuclepore filter. This encouraged us to try various approaches using chloroform to clear the Nuclepore filters.

(a) When applying a drop of chloroform directly on a filter, the filter clears but the fibers migrate to the periphery, making it impossible to discern individual fibers.

(b) By sandwiching the fibers on the field sample between another filter, we were successful in keeping the fibers from shifting to the periphery of the chloroform, but small air bubbles are trapped between the filters making it difficult to count fibers. The chloroform also causes the filter to wrinkle. Once the wrinkling occurs, counting is impossible.

TABLE B-3. ATOMIC ABSORPTION AND ROYCO DATA COMPARISON

Sample I.D.	Sampling Time (min)	Mg Conc. in Stack ($\mu g/cm^3 \times 10^6$)	Asbestos Conc. in Stack* ($\mu g/cm^3 \times 10^6$)	Royco Count** ($part./cm^3$)	Asbestos Conc./Royco count ($\mu g/part. \times 10^6$)
2-2	2	0.23	0.9	0.7	1.3
2-8	8	0.32	1.3	1.4	0.93
3-10	10	0.37	1.5	1.4	1.1
1-30	30	0.67	2.7	3.6	0.75

* $$\text{Asbestos Conc.} = \frac{[(Mg_{AA} - Mg_{background})_{AA} (\text{Solution Vol.})_{AA}] [\text{Asbestos/Mg Ratio}]}{[\text{Air Sampling Time}][\text{Air Flow Rate}][\text{Filter Area}]_{AA}}$$

** Royco Count = [(Royco Range)(Count)][Asbestos/Total Particulate Ratio]

(c) Duco cement, insoluble in chloroform, is used to reduce wrinkling by gluing down the periphery of the filter. This method helps slightly but counting the fibers is still very difficult.

(d) The fibers are sandwiched between Millipore and Nuclepore filters. A few drops of chloroform are placed over the Nuclepore filter to dissolve it and then the Millipore filter is cleared (JM technique). The fibers still move toward the periphery.

(e) To solve the problem of movement of the fibers, suction is applied on the filter sandwich before the chloroform is added, but this effort also failed to prevent migration.

At this point, no further efforts to clear the membranes were employed.